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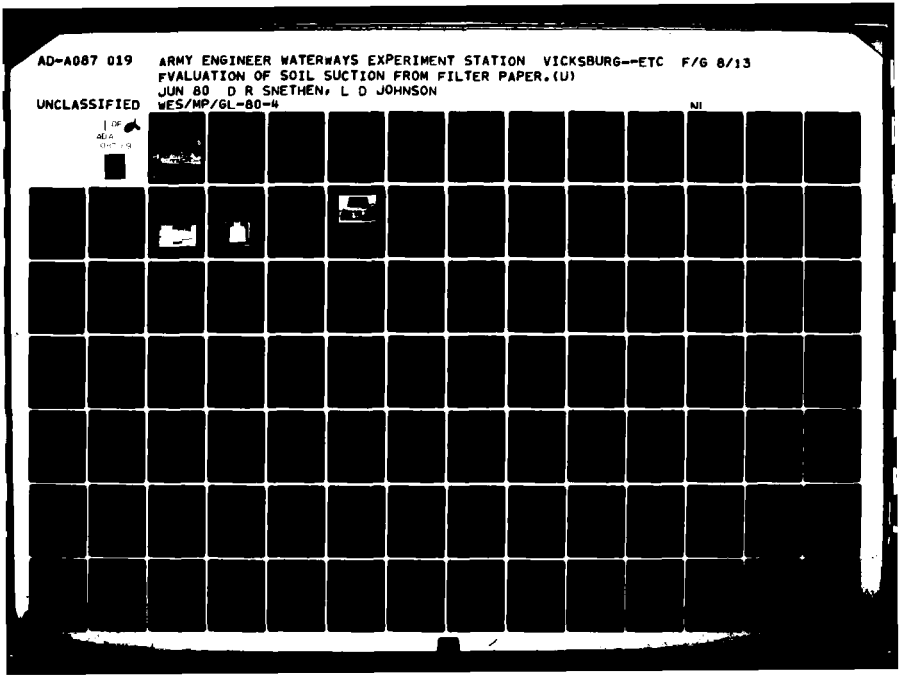

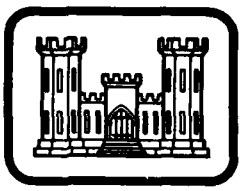

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EVALUATION OF SOIL SUCTION FROM FILTER PAPER

by

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June 1980
Final Report

Prepared for Assistant Secretary of the Army (R&D)
Washington, D. C. 20310

Under Project No. 4A161101A91D, Task 02

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Soil suction is a useful parameter for characterizing the effect of moisture on the volume change behavior of cohesive soil. Soil suction can be described as a measure of the pulling or tension force per unit area exerted on pore water. Two often-used energy methods for determining soil suction are the thermocouple psychrometer method and the filter paper method.

In this study, laboratory suction tests were performed on 24 undisturbed soil samples to evaluate the filter paper method with respect to → (continued)

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20. ABSTRACT (Continued)

the thermocouple psychrometer method. The filter paper method is simple and requires little special equipment; however, the validity of filter paper as a useful tool for characterizing swelling behavior has not been well-established.

The results of the study show that the filter paper method, as it was employed in this study, is as reproducible as the thermocouple psychrometer method. For the soils tested, comparisons of parameters generally found useful for characterizing swelling behavior showed that the filter paper method usually indicates less capability for swell than the thermocouple psychrometer method. This conclusion is especially significant since predictions of heave based on suction data from thermocouple psychrometers indicate higher levels of heave than those actually determined in the field.

PREFACE

The study described in this report was performed under Project No. 4A161101A91D, Task 02, sponsored by the Assistant Secretary of the Army (R&D) as part of the In-House Laboratory Independent Research (ILIR) Program.

The work was conducted during the period October 1978-March 1980 at the U. S. Army Engineer Waterways Experiment Station (WES), Vicksburg, Miss. Dr. Donald R. Snethen, Associate Professor of Civil Engineering, Oklahoma State University, conceived the project and completed the laboratory investigation while employed at WES. Dr. Lawrence D. Johnson, Research Group (RG), Soil Mechanics Division (SMD), Geotechnical Laboratory (GL), WES, analyzed the results and prepared the report. Mr. Arden P. Park, Soil Testing Branch, SMD, prepared the computer program and assisted with the analysis. Dr. Paul F. Hadala, Acting Assistant Chief, GL, and Dr. Edward B. Perry and Mr. Walter C. Sherman, Jr., RG, SMD, reviewed the report and provided many helpful comments. Mr. Clifford L. McAnear was Chief, SMD, and Mr. James P. Sale was Chief, GL.

Directors of WES during the conduct of the study and preparation of this report were COL J. L. Cannon, CE, and COL N. P. Conover, CE. Technical Director was Mr. F. R. Brown.

CONTENTS

CONVERSION FACTORS, INCH-POUND TO METRIC (SI) UNITS OF MEASUREMENT

Inch-pound units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
feet	0.3048	metres
inches	2.54	centimetres
tons (force) per square foot	95.76052	kilopascals

EVALUATION OF SOIL SUCTION FROM FILTER PAPER

PART I: INTRODUCTION

Background

1. Soil suction has been shown to be a very useful parameter for characterizing the effect of moisture on the volume change behavior of soil (Johnson 1978, Johnson and Snethen 1978) and also appears promising for characterizing the strength of cohesive soil. This should be expected because soil suction is essentially a measure of the energy available to the natural microscale mechanisms that cause changes in soil volume. All processes and chemical reactions of which the natural microscale mechanisms are a part use energy. The two natural microscale mechanisms that play the greatest role in causing volume change are clay particle attraction and cation hydration (Snethen, Johnson, and Patrick 1977).

2. The Corps of Engineers is interested in soil suction as a relatively quick and inexpensive method for predicting potential heave of road and building foundations. Such predictions of heave are extremely valuable in the design of roads and buildings as an aid in minimizing the effects of soil heave on these structures. Filter paper has been shown to be a useful tool for measuring soil suction in agronomy and agricultural applications (Gardner 1937, McQueen and Miller 1968). It is possible that filter paper may also be applicable to the prediction of potential heave in swelling soils.

Definition of Soil Suction

3. The amount of work that must be done per unit of pure water to transport reversibly and isothermally an infinitesimal quantity of water from a pool of pure water at a specified elevation at atmospheric

pressure to the soil water is called the "potential" of the water (Aitchison 1965). The total suction, which results from this potential, is defined in Table 1. Soil suction quantitatively describes the interaction between soil particles and water, which determines the behavior of the soil mass. It is the force per unit area responsible for holding water in the soil and is a measure of the pulling or tension stress exerted on the pore water. The soil suction is formally called total soil suction; however, soil moisture suction or simply "suction" is generally preferred.

4. The total soil suction is defined as the sum of the matrix τ°_{m}* and osmotic τ°_{s} suctions

$$\tau^{\circ} = \tau^{\circ}_{m} + \tau^{\circ}_{s} \tag{1}$$

The superscript $^{\circ}$ means that the soil is not subject to any confining pressure, except atmospheric pressure. The matrix suction τ°_{m} is related to the geometrical configuration of the soil and structure, capillary tension in the pore water, and water sorption forces of the clay particles. The osmotic suction τ°_{s} is caused by the concentration of soluble salts in the pore water. The effect of the osmotic suction on swell is not well known, but an osmotic effect may be observed if the concentration of soluble salts in the pore water differs from that of the externally available water; i.e., swell may occur in the specimen if the external water contains less soluble salts than the pore water. The effect of the osmotic suction on swell behavior is usually assumed small compared to the effect of the matrix suction.

Evaluation of Soil Suction

5. Two approaches have commonly been used for evaluation of soil suction: the mechanistic approach and the energy (or potential)

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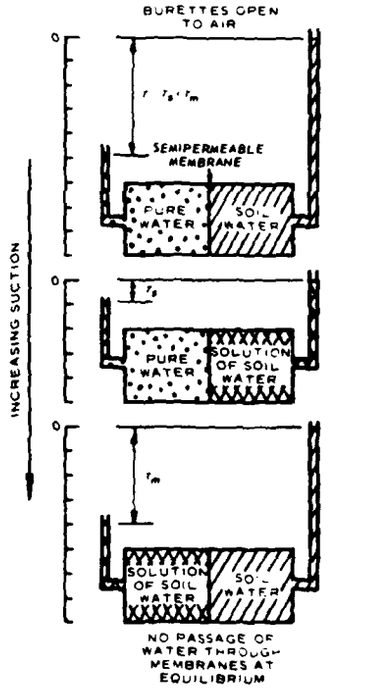
* For convenience, mathematical symbols are listed and defined in the Notation (Appendix C).

Table 1

Definitions of Suction

Term	Symbol	Definition*	Illustration
Total suction	τ	The negative gage pressure, relative to the external gas pressure** on the soil water, to which a pool of pure water must be subjected in order to be in equilibrium through a semipermeable (permeable to water molecules only) membrane with the soil water	
Osmotic (solute) suction	τ_s	The negative gage pressure to which a pool of pure water must be subjected in order to be in equilibrium through a semipermeable membrane with a pool containing a solution identical in composition with the soil water	
Matrix (soil water) suction	τ_m	The negative gage pressure, relative to the external gas pressure** on the soil water, to which a solution identical in composition with the soil water must be subjected in order to be in equilibrium through a porous permeable wall with the soil water	



* From Aitchison (1965).

** The magnitude of the matrix suction is reduced by the magnitude of the external gas pressure. The osmotic suction is determined by the concentration of soluble salts in the pore water and can be obtained from $\tau_s = RT/v \log_e p/p_o$ where R is the ideal gas constant, T is absolute temperature, v is volume of a mole of liquid water, p is vapor pressure of the pore water in the soil, and p_o is vapor pressure of free pure water.

approach. The mechanistic approach is based on measurements of negative pore water pressure in specimens using special consolidometers and pressure membrane devices. The energy approach, the subject of this report, is applicable to the evaluation of soil suction from measurement of the relative humidity in the soil. The two approaches appear to provide equivalent soil suctions as long as the concentration of soluble salts in the pore water is negligible; i.e., the negative pore water pressure and the matrix suction appear equivalent (Johnson 1973, Verbrugge 1976). The energy approach will provide larger suctions in the presence of soluble salts. Experience (Johnson 1974, 1978; Johnson and Snethen 1978) shows that the energy approach is simpler, less time-consuming, and more economical than the mechanistic approach.

6. The energy approach is founded on thermodynamics. In this approach, the force per unit area that causes available water to move into soil is linearly related to the free energy of the soil water relative to the available water outside of the soil. The free energy Δf needed to move free pure water into the pores of soil containing the soil water is (Aitchison 1965)

$$\Delta f = RT \log_e \frac{p}{p_o} \tag{2}$$

where

R = ideal gas constant (86.82 cc-tsf/K-mole)

T = absolute temperature, K

p = vapor pressure of the pore water in the soil, tsf

p_o = vapor pressure of free pure water, tsf

p/p_o = relative humidity

7. The change in free energy due to movement of the free pure water into the pore water is usually given in terms of an equivalent total soil suction or suction stress

$$\tau^\circ = \frac{RT}{v} \log_e \frac{p}{p_o} \tag{3}$$

where v is the volume of a mole of liquid water (18.02 cc/mole). The total soil suction has been defined as the sum of the osmotic and matrix components (Equation 1 and Table 1). Because the osmotic suction originates from the concentration of soluble salts in the pore water, it is related to the osmotic repulsion mechanism (Snethen, Johnson, and Patrick 1977), and it may be expressed by

$$\tau_s^\circ = \tau_s = \frac{RT}{v} \log_e \frac{p_s}{p_o} \tag{4}$$

where p_s is the vapor pressure of the free pore water solution, in tons per square foot. The superscript $^\circ$ is not needed because the osmotic suction does not change with confining pressure.

8. The matrix suction in clay soils is related to forces from clay particle attraction and cation hydration in addition to surface tension effects (Snethen, Johnson, and Patrick 1977) and may be expressed by

$$\tau_m^\circ = \frac{RT}{v} \log_e \frac{p}{p_s} \tag{5}$$

The matrix suction can be evaluated directly from the relative humidity of the soil p/p_o when the chemical composition of the pore water contributes negligible osmotic suction. The matrix suction of the pore water, being a measure of the negative pore water pressure, will become less negative with increasing confining pressure on the soil. Suctions, although negative quantities, are commonly expressed as positive values. This convention is followed in this report.

9. Two often-used methods based on the energy approach for determining the total soil suction are the thermocouple psychrometer method and the filter paper method. The thermocouple psychrometer method is adapted from a technique originally proposed by Spanner (1951), while the filter paper method was adapted by McQueen and Miller (1968) from a technique proposed by Gardner (1937). The suction range of

thermocouple psychrometers is usually between 1 and 100 tsf,* while the range of filter paper varies from less than 0.1 to more than 1000 tsf. Past experience had shown that at least 2 days is required to reach moisture equilibrium with thermocouple psychrometers (Johnson 1974), while 7 days is required for moisture equilibrium with the filter paper method (McQueen and Miller 1968). The difference in time is related to the greater sensitivity of filter paper at low suctions compared to thermocouple psychrometers (this will be shown later). The thermocouple psychrometer method has been shown to be simple and accurate within its range (Johnson 1978).

10. The filter paper method is less complicated than the thermocouple psychrometer method; however, very small changes in weight are involved with the filter paper method such that this method is susceptible to large error, particularly if systematic weighing procedures are not followed. Validation of the filter paper method would be significant because this technique is very simple and does not require special equipment, except for a gravimetric scale accurate to 0.001 g. Most laboratory technicians can be trained to perform the test procedure with little effort.

11. Both the thermocouple psychrometer method and the filter paper method require calibration curves to determine the soil suction from test results. Calibration is usually performed with salt solutions such as sodium or potassium chlorides of various known molality that produce a given relative humidity. The relative humidities are subsequently converted to total soil suction by Equation 3.

Purpose and Scope

12. The purpose of this study was to validate the concept of using filter paper for evaluation of soil suctions to be used in applications of estimating potential heave as an aid to pavement and

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* A table of factors for converting inch-pound units of measurement to metric (SI) units is presented on page 3.

foundation design. The study was limited in scope to the determination of the total soil suction-water content relationships of 24 different soils by both the thermocouple psychrometer method and the filter paper method. Comparisons of results obtained using the two methods were made to determine if the two methods give the same answer. Since the thermocouple psychrometer method was a priori assumed valid, close agreement by the filter paper test results would be considered to validate the specific version of the filter paper concept tested here.

PART II: DESCRIPTION OF TEST PROCEDURES

Apparatus and Procedures

Thermocouple psychrometer

13. The thermocouple psychrometer measures relative humidity in soil by a technique called Peltier cooling. If a current is caused to flow through a single thermocouple junction in the proper direction, that particular junction will cool, causing water to condense on it when the dew point is reached. Condensation of this water inhibits further cooling of the junction. The voltage developed between the thermocouple and reference junctions is proportional to the temperature difference and is measured by a microvoltmeter. Because relative humidity is a function of the dew point and the ambient temperature, the voltage output can be related to relative humidity or soil suction by a calibration curve.

14. Laboratory measurements to evaluate total suction by thermocouple psychrometers may be made with the apparatus shown in Figure 1.

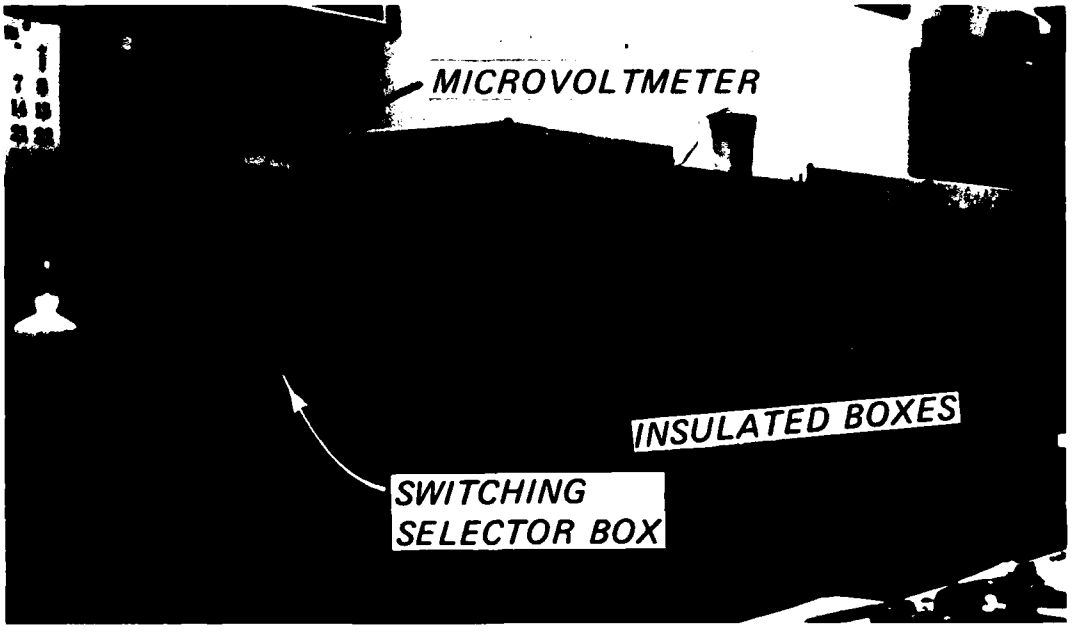

Figure 1. Thermocouple psychrometer apparatus

Each of the four cubical boxes is insulated with a 2-in. thickness of polystyrene. The inside dimensions are slightly less than 1 ft on a side and allow placement of nine 300-ml Teflon containers inside (Figure 2). One thermocouple psychrometer is inserted into a container with the calibration solution or soil specimen and the container sealed with a No. 14 rubber stopper. The rubber stoppers require some machining to insure a tight seal. Equilibrium of the relative humidity in the sealed sample containers, as measured by the psychrometer, is usually obtained after 2 days.

15. The monitoring system (Figure 1) includes an MJ55 Wescor psychrometric microvoltmeter with a range in the maximum scale between 1 μV and 1000 V . The microvoltmeter includes the necessary cooling circuit. The microvoltmeter should have a maximum range of at least 30 μV and allow readings to 0.1 μV . The switching selector box (located beneath the microvoltmeter and to the left of the insulted boxes in Figure 1) serves to connect each psychrometer with the microvoltmeter.

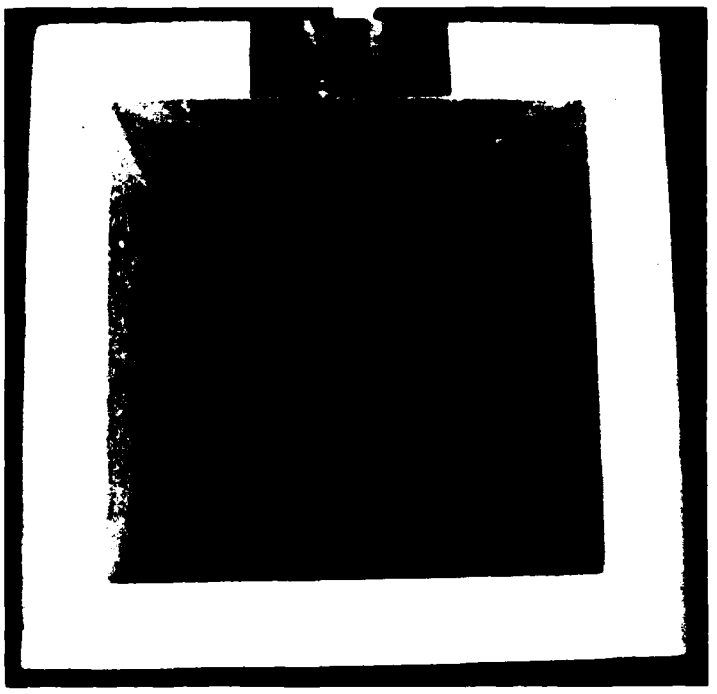

Figure 2. View inside of an insulated box

The cooling current is applied for 15 seconds to each psychrometer by a toggle switch on the microvoltmeter. Release of the toggle switch transfers the function from cooling to the readout circuit. The maximum reading on the microvoltmeter scale is then recorded.

16. The readings of the microvoltmeter are usually taken at room temperature, preferably between 20 and 25°C, and corrected to a standard microvolt output by

$$E_{25} = \frac{E_t}{0.325 + 0.027t} \tag{6}$$

where

E_{25} = microvolts at 25°C
E_t = microvolts at t° C
t = measured temperature, °C

Temperature readings, made by either a thermometer or a thermocouple, need to be within 3°C for accurate computation of the soil suction.

Filter paper

17. The filter paper method involves enclosing pretreated filter paper with a calibration solution or a soil specimen in an airtight container (Figure 3) until complete relative humidity equilibrium is reached. Corrosion-resistant metal or Teflon containers may be placed in a large insulated chest such as shown in Figure 3 for storage. A thermometer is included during calibration to determine the temperature. After 7 days in storage, the water content in percent of the dry weight of the filter paper is determined and the soil suction obtained from a calibration curve. The equilibration time was originally determined by McQueen and Miller (1968) and confirmed by preliminary tests. Prior to calibration or testing, a 2.2-in.-diam filter paper disc is pretreated with 3 percent pentachlorophenol in ethanol (to inhibit bacterial deterioration) and allowed to air-dry before using.

18. Care is required to keep the filter paper from becoming contaminated with soil from the specimen, free water, or other contaminant. The most common source of contamination was found to occur when enclosing filter paper with a wetted soil specimen. The filter paper may

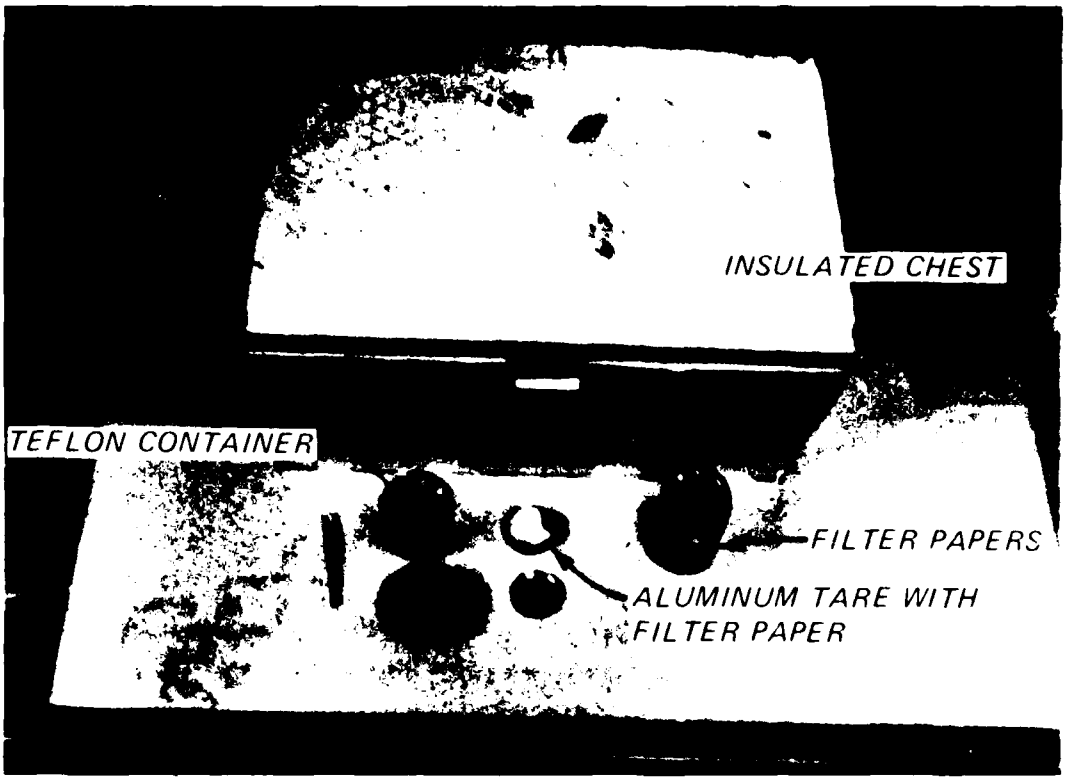

Figure 3. Filter paper apparatus

absorb excessive moisture if in contact with either the specimen or with free water. Contamination problems occur less frequently when testing soil specimens dry of natural water content.

19. After 7 days in the airtight container with the soil specimen, the filter paper is transferred to a 2-in.-diam covered aluminum tare (Figure 3) and weighed immediately on a gravimetric scale accurate to 0.001 g. The number of filter papers and tares weighed at one time should be kept small (e.g., nine or less) to minimize error due to water evaporating from the filter paper. The tare is opened and placed in an oven for at least 24 hours at a temperature of 110°C. The ovendry weight of the filter paper is then determined by a carefully regulated procedure described in paragraph 24.

Calibration Techniques

Salt solutions

20. Calibration of thermocouple psychrometers and filter paper may be conveniently accomplished using known molalities of salt solutions, such as sodium and potassium chlorides. Table 2 illustrates the suctions that would be in equilibrium with the shown molalities of sodium chloride salt solutions for temperatures of 15, 20, 25, and 30°C. The source of data for Table 2 is the International Critical Tables (Frazer, Taylor, and Grollman 1928).

Table 2

Calibration Salt Solutions

Measured Temperature, t, °C	Suction, tsf For Cited Molality of Sodium Chloride Solution						
	0.053	0.100	0.157	0.273	0.411	0.550	1.000
15	3.05	4.67	7.27	12.56	18.88	25.29	46.55
20	3.10	4.74	7.39	12.75	19.22	25.76	47.50
25	3.15	4.82	7.52	13.01	19.55	26.23	48.44
30	3.22	4.91	7.64	13.22	19.90	26.71	49.37

21. The salt solutions of known molality may be placed in small containers of polystyrene, Teflon, stainless steel, or other noncorrosive material. These cups are subsequently enclosed in larger sealed containers with thermocouple psychrometers or filter paper until the relative humidity in the psychrometers or filter paper is in equilibrium with the relative humidity of the salt solutions. The temperature is also recorded to determine the suction from Table 2.

Calibration curves

22. Thermocouple psychrometers. The calibration curve of each psychrometer may be expressed by

$$\tau^{\circ} = aE_{25} - b \qquad (7)$$

where

τ° = total soil suction, tsf

a,b = calibration constants

E_{25} = pyschrometric microvoltmeter reading corrected to 25°C, μV

Table 3 presents equations for the calibration curves of each of the psychrometers as experimentally determined using the salt solutions mentioned above. Each curve is reproducible to approximately 3 tsf for suctions between 3 and 50 tsf. This reproducibility is not as good at low suction levels as the 5 percent obtained with other equipment

Table 3

Equations for the Psychrometer Calibration Curves

(30 March 1979 Data)

Psychrometer No.	Calibration Equation	Psychrometer No.	Calibration Equation
1	$\tau = 2.75E_{25} - 0.8$	19	$\tau = 2.84E_{25} - 0.3$
2	$\tau = 2.48E_{25} - 0.2$	20	$\tau = 2.61E_{25} - 1.9$
3	$\tau = 3.94E_{25} - 3.4$	21	$\tau = 2.51E_{25} - 0.1$
4	$\tau = 2.83E_{25} - 1.2$	22	$\tau = 2.85E_{25} - 7.4$
5	$\tau = 2.95E_{25} - 3.4$	23	$\tau = 2.59E_{25} - 0.4$
6	$\tau = 2.75E_{25} - 2.5$	24	$\tau = 3.12E_{25} - 2.5$
7	$\tau = 2.70E_{25} - 0.1$	25	$\tau = 2.70E_{25} - 1.6$
8	$\tau = 2.70E_{25} - 0.4$	26	$\tau = 2.84E_{25} - 0.6$
9	$\tau = 2.60E_{25} - 0.1$	27	$\tau = 2.60E_{25} - 7.2$
10	$\tau = 2.73E_{25} - 0.1$	28	$\tau = 2.54E_{25} - 3.9$
11	$\tau = 2.75E_{25} - 0.1$	29	$\tau = 3.10E_{25} - 3.9$
12	$\tau = 2.60E_{25} - 0.3$	30	$\tau = 2.61E_{25} - 0.4$
13	$\tau = 3.55E_{25} - 2.0$	31	$\tau = 2.45E_{25} - 2.5$
14	$\tau = 2.86E_{25} - 1.2$	32	$\tau = 2.60E_{25} - 2.2$
15	$\tau = 2.70E_{25} - 3.4$	33	$\tau = 2.81E_{25} - 3.0$
16	$\tau = 2.93E_{25} - 2.8$	34	$\tau = 2.88E_{25} - 1.1$
17	$\tau = 3.06E_{25} - 4.0$	35	$\tau = 2.82E_{25} - 1.0$
18	$\tau = 2.58E_{25} - 4.2$	36	$\tau = 2.90E_{25} - 2.3$

using metal rather than Teflon containers (Johnson 1974, 1978).

23. Filter paper. The calibration curve for the filter paper method was found to be dependent on the handling procedure adopted and used following removal of the filter paper from the drying oven, as well as other variables.

24. Figure 4 illustrates four such calibration curves. The calibration curves are bounded by the McQueen and Miller (1968) and the WES II curves. The McQueen and Miller curve was obtained by weighing the filter paper within 5 sec following removal from the oven. The Miller (1978) curve was obtained using the most reliable portions of

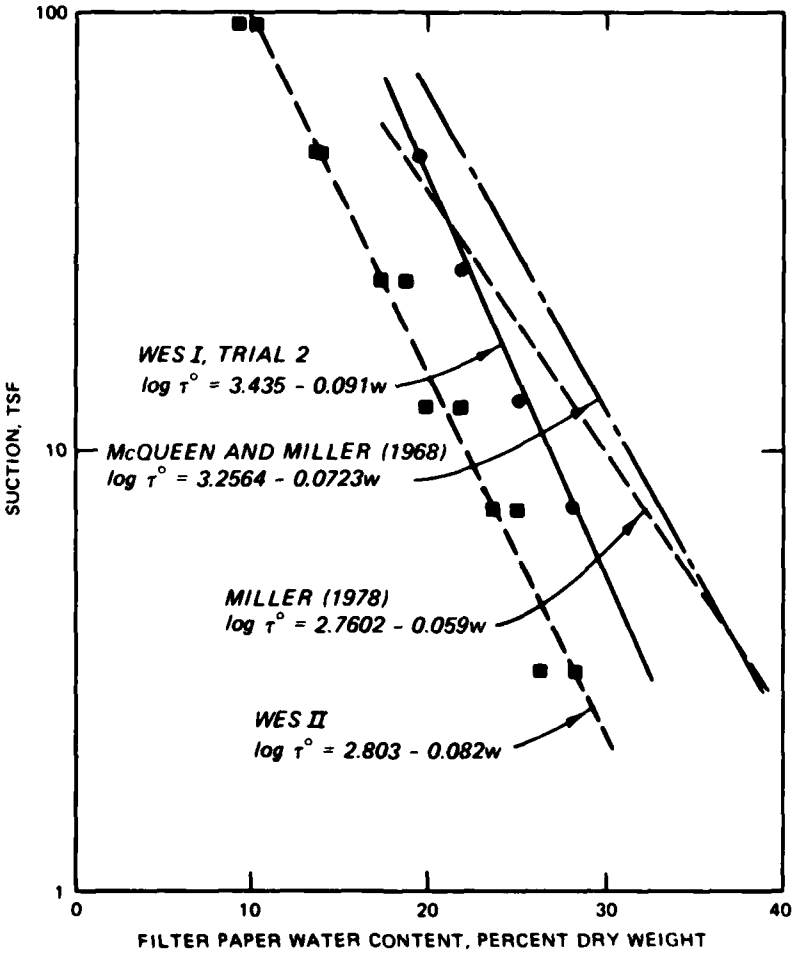

Figure 4. Calibration curves for filter paper

calibration data reported by McQueen and Miller (1968) and Al-Khafaf and Hanks (1974). The WES I curve was obtained by covering the ovendried specimens following removal from the drying oven and weighing within 15 minutes. (See Appendix A for details of the WES I calibration procedure.) The WES II curve was obtained by not covering the ovendried specimens and then weighing from 15 minutes to 4 hours following removal from the oven (Johnson 1980). Changes in filter paper weights due to exposure to the salt solutions are normally small (e.g., <0.1 g) and require accurate scale calibration. In general, all the curves are steep and not conducive to accurate evaluation of suction. It is apparent from these calibration curves that accurate evaluation of soil suction using filter paper requires careful adherence to a single standardized testing procedure.

Soil Testing

25. Specimens from 24 undisturbed soil samples were selected for testing. Classification indices for these specimens are shown in Table 4. Half of each 3- by 5.5-in. sample was used for the thermocouple psychrometer tests, while the remaining portion was used in the filter paper tests.

26. The total soil suction-water content relationship for each soil was determined using both the thermocouple psychrometer method and the filter paper method. The desired range in water content was provided by testing several 1-in. pieces of undisturbed material. Nine specimens were used to determine each suction-water content relationship. The range in water content was obtained by adding small amounts of distilled water to some of the soil specimens and air-drying others for various lengths of time. The filter paper procedure followed (Appendix A) required removal from the oven and weighing within 15 minutes.

27. The multipoint total soil suction-water content relationships may be plotted as shown in Appendix B for each undisturbed sample. A least-squares straight line was drawn through the points as illustrated

Table 4

Soil Classification Data

Sampling Site	Boring No.	Sample No.	Depth ft	Geologic Formation	Grain Size Distribution percent passing		Specific Gravity G_s	Natural Water Content w percent	Atterberg Limits			Soil Classification	
					No. 200 Sieve	2-μm Sieve			Liquid Limit	Plastic Limit	Plasticity Index	USCS*	AASHTO**
Jackson, Miss.	U-2	4	7.2-9.4	Yazoo	98	76	2.83	39.4	128	28	100	CH	A-7-5
Hattiesburg, Miss.	U-2	4	6.6-7.8	Hattiesburg	96	44	2.74	23.0	54	18	56	CH	A-7-6
Monroe, La.	U-1	3	5.6-7.4	Alluvial material	96	58	2.82	33.5	77	24	53	CH	A-7-6
Lake Charles, La.	U-2	4	6.8-8.9	Prairie Terrace material	94	28	2.74	20.6	38	14	24	CL	A-6
San Antonio, Tex.	U-2	9	10.9-13.1	Taylor	98	47	2.70	37.4	80	30	50	CH	A-7-6
Vernon, Tex.	U-1	7	9.9-11.3	Vale	98	64	2.88	11.5	48	22	26	CL	A-7-6
Durant, Okla.	U-2	4	6.6-9.2	Washita	99	60	2.81	18.7	63	21	42	CH	A-7-6
Hennessey, Okla.	U-1	4	6.8-8.8	Hennessey	99	47	2.82	12.9	42	20	22	CL	A-7-6
Holbrook, Ariz., Site 1	U-2	4	6.7-8.5	Chinle	96	26	2.78	8.2	47	20	27	CL	A-7-6
Holbrook, Ariz., Site 2	U-2	4	6.8-9.0	Chinle	92	46	2.82	11.8	71	26	45	CH	A-7-6
Price, Utah	U-2	5	8.2-10.4	Mancos	98	37	2.75	3.7	44	16	28	CL	A-7-6
Hayes, Kan.	U-2	4	6.4-8.5	Blue Hill	94	59	2.88	22.0	82	21	61	CH	A-7-6
Ellsworth, Kan.	U-2	3	6.0-7.9	Graneros	94	27	2.77	28.2	86	38	48	CH	A-7-5
Limon, Colo., Site 1	U-2	4	7.4-8.8	Pierre	97	51	2.84	19.7	67	20	47	CH	A-7-6
Limon, Colo., Site 2	U-2	3	5.5-7.8	Laramie	97	49	2.84	29.4	87	26	61	CH	A-7-6
Denver, Colo.	U-3	4	5.7-7.8	Denver	90	33	2.80	16.8	68	22	46	CH	A-7-6
Newcastle, Wyo., Site 1	U-2	4	7.3-9.8	Mowry	98	39	2.63	13.2	73	24	49	CH	A-7-6
Newcastle, Wyo., Site 2	U-2	4	6.1-8.3	Pierre	99	55	2.80	16.4	77	19	58	CH	A-7-6
Billings, Mont.	U-2	4	6.7-9.2	Bearpaw	99	42	2.76	15.4	69	19	50	CH	A-7-6
Reliance, S. D.	U-1	5	8.0-10.6	Pierre	95	47	2.80	34.9	110	34	76	CH	A-7-5
Flagstaff, Ariz., Sta 672	U-1	8	8.35-9.75	Chinle	65	28	2.81	6.2	86	17	69	CH	A-7-6
Flagstaff, Ariz., Sta 861	U-3	7	11.7-13.7	Chinle	97	38	2.82	12.6	48	23	25	CL	A-7-6
Lackland AFB, Tex.	U-3	3	5.7-7.3	Upper Midway	92	34	2.74	21.2	55	17	38	CH	A-7-6
Fort Carson, Colo.	C-1	10	9.4-10.6	Pierre	86	30	2.74	12.3	39	15	24	CL	A-6

* Unified Soil Classification System.

** American Association of State Highway and Transportation Officials.

to obtain an equation for the curves

$$\log \tau^{\circ} = A - Bw \tag{8}$$

where

w = soil water content, percent dry weight

A,B = soil suction parameters

The constants A and B have been shown to characterize the relative swelling capability of the soil (Johnson 1978, Snethen 1979). Although other relationships may exist between soil suction and water content, and possibly even provide a better fit of data, the form of Equation 8 is chosen because it provides characterization of swelling behavior analogous to conventional void ratio-log pressure consolidation curves. A total of five plots are shown in Appendix B for each soil sample: one plot for the thermocouple psychrometer test results, and four plots for the four different calibration curves of the filter paper method. The data from which the plots were made are also shown in Appendix B. Curve WES I was expected to be the most appropriate calibration curve since the procedure used to determine the soil suction from filter paper was similar to the WES I calibration procedure.

PART III: ANALYSIS OF RESULTS

28. The results of the statistical analysis are summarized in Table 5. Table 5 includes an additional calibration curve, WES III, which is compared to all the other filter paper calibration curves in Figure 5. It was obtained by fitting the filter paper calibration curve to achieve the closest agreement of the filter paper data for the 24 undisturbed samples with the thermocouple psychrometer data for the corresponding samples. This was done by plotting on a single figure (Figure 5) a calculated soil suction versus filter paper water content for each soil. The suction for each soil was calculated by substituting into the thermocouple psychrometer equation of each soil given in Appendix B the water content of the soil corresponding to or in equilibrium with the water content of the filter paper. The coefficient of determination r^2 of the WES III curve in Figure 5 is 0.74, indicating that the semilog form of the equation chosen is only roughly descriptive of the trend of the data. The r^2 is an indication of linearity in which $r^2 = 1$ data represent a straight line while $r^2 = 0$ data are random.

29. Figure 5 shows that the Miller (1978) curve fits the data points better than the remaining curves, other than the WES III curve which was force-fitted to the data. The WES II curve represents the boundary of minimum suction, which is expected in view of the laboratory testing procedure leading to the WES II curve. The WES III (fitted) and Miller calibration curves should provide the best correlations with the thermocouple psychrometer soil suction data.

30. The relatively flat slope of the WES III calibration curve compared to the other curves suggests two possibilities: (a) the lower soil suctions measured by the thermocouple method were not low enough or (b) the filter paper became excessively wet when testing wetted soil specimens. Possibility (a) may be caused by inadequate moisture equilibrium within the soil containers used in the thermocouple psychrometer method as well as insensitivity at low suctions. An independent study (Johnson 1980) shows that there is a tendency for the

Table 5

Soil Suction Characterization Parameters

Sampling Site	Calibration Curve*	Characterization Parameters: Ordinate Intercept A	Slope B	Coefficient of Determination r^2	Initial Conditions: Water Content percent	Soil Suction tsf
Jackson, Miss.	TP	2.3514	0.0278	0.447	42.0	15.3
Depth: 7.2-9.4 ft	M&M	5.5437	0.1007	0.898		20.6
Boring: U-2	M	4.6268	0.0821	0.898		15.1
Sample: 4	WES I	6.3139	0.1267	0.898		9.8
	WES II	5.3972	0.1142	0.898		4.0
	WES III	4.1889	0.0670	0.898		23.7
Hattiesburg, Miss.	TP	0.9659	-0.0031	0.002	22.3	12.0
Depth: 6.6-7.8 ft	M&M	9.6448	0.4305	0.529		1.1
Boring: U-2	M	8.8516	0.3930	0.521		1.2
Sample: 4	WES I	8.1353	0.3835	0.484		0.4
	WES II	6.3054	0.3100	0.499		0.3
Monroe, La.	TP	1.6771	0.0143	0.096	35.0	15.0
Depth: 5.6-7.4 ft	M&M	4.6695	0.0930	0.688		26.0
Boring: U-1	M	3.9133	0.0759	0.688		18.0
Sample: 3	WES I	5.2136	0.1171	0.688		13.0
	WES II	4.4057	0.1055	0.688		5.2
	WES III	4.2394	0.0809	0.687		25.6
Lake Charles, La.	TP	1.1092	0.0054	0.004	20.0	10.0
Depth: 6.8-8.9 ft	M&M	6.6682	0.3103	0.652		2.9
Boring: U-2	M	6.7279	0.3117	0.645		3.1
Sample: 4	WES I	3.9232	0.2023	0.624		0.8
	WES II	2.4449	0.1428	0.573		0.4
San Antonio, Tex.	TP	2.3063	0.0351	0.336	36.0	11.0
Depth: 10.9-13.1 ft	M&M	4.9849	0.1081	0.298		12.4
Boring: U-2	M	4.1707	0.0882	0.298		9.9
Sample: 9	WES I	5.5273	0.1334	0.306		5.3
	WES II	4.5153	0.1147	0.325		2.4
Vernon, Tex.**	TP	4.6399	0.2503	0.931	12.5	30.0
Depth: 9.9-11.3 ft	M&M	16.2038	1.1443	0.938		80.0
Boring: U-1	M	14.5919	1.0348	0.937		45.0
Sample: 7	WES I	16.6595	1.1157	0.920		55.0
	WES II	12.9648	0.9373	0.909		18.0
	WES III	11.0937	0.7470	0.764		57.0
Durant, Okla.	TP	2.2964	0.0795	0.183	16.6	9.5
Depth: 6.6-9.2 ft	M&M	9.9979	0.5794	0.590		2.4
Boring: U-2	M	9.4298	0.5480	0.610		2.2
Sample: 4	WES I	8.2492	0.4902	0.550		1.3
	WES II	6.3976	0.3924	0.555		0.8
Hennessey, Okla.	TP	6.4425	0.3384	0.532	15.0	23.3
Depth: 6.8-8.8 ft	M&M	1.6362	0.0736	0.498		50.0
Boring: U-1	M	1.0431	0.0411	0.002		30.0
Sample: 4	WES I	1.9041	0.1010	0.011		30.0
	WES II	1.4483	0.0872	0.012		11.0
Holbrook, Ariz., Site 1**	TP	3.5207	0.1966	0.615	9.5	45.0
Depth: 6.7-8.5 ft	M&M	4.7863	0.3032	0.843		80.5
Boring: U-2	M	4.0086	0.2474	0.843		45.5
Sample: 4	WES I	5.3605	0.3816	0.843		54.4
	WES II	4.5381	0.3439	0.843		18.7
	WES III	3.7925	0.2152	0.843		56.0

(Continued)

* TP denotes thermocouple psychrometer; M&M, McQueen and Miller (1968); M, Miller (1978).
** Data included in cor-elations between thermocouple psychrometer and filter paper methods.

(Sheet 1 of 3)

Table 5 (Continued)

Sampling Site	Calibration Curve	Characterization Parameters: Ordinate Intercept A	Slope B	Coefficient of Determination r^2	Water Content percent	Soil Suction tsf
Holbrook, Ariz., Site 2**	TP	4.4100	0.1558	0.975	15.5	98.9
Depth: 6.8-9.0 ft	M&M	9.2626	0.4476	0.763		211.3
Boring: U-2	M	7.6615	0.3653	0.763		99.9
Sample: 4	WES I	10.9946	0.5634	0.763		182.8
	WES II	9.6150	0.5077	0.763		55.7
	WES III	6.0189	0.2584	0.500		103.2
Price, Utah**	TP	3.0341	0.2608	0.892	4.2	86.8
Depth: 8.2-10.4 ft	M&M	9.9730	1.8717	0.742		120.9
Boring: U-2	M	8.8645	1.6801	0.734		64.3
Sample: 5	WES I	9.8842	1.8647	0.765		112.8
	WES II	8.1941	1.5773	0.772		37.1
	WES III	4.9935	0.6953	0.817		118.4
Hayes, Kan.**	TP	4.2837	0.1478	0.919	19.7	23.6
Depth: 6.4-8.5 ft	M&M	4.6978	0.1684	0.872		24.0
Boring: U-2	M	3.9364	0.1374	0.872		17.0
Sample: 4	WES I	5.2492	0.2120	0.872		11.8
	WES II	4.4377	0.1910	0.872		4.7
	WES III	3.6845	0.1153	0.872		25.9
Ellsworth, Kan.**	TP	3.4202	0.0568	0.604	39.9	14.3
Depth: 6.0-7.9 ft	M&M	23.7498	0.5882	0.677		1.9
Boring: U-2	M	19.4837	0.4800	0.677		2.2
Sample: 3	WES I	25.4478	0.6430	0.656		0.6
	WES II	20.8580	0.5333	0.657		0.4
	WES III	11.2458	0.2583	0.602		8.7
Limon, Colo., Site 1**	TP	3.2847	0.0888	0.899	19.2	38.0
Depth: 7.4-8.8 ft	M&M	4.2655	0.1334	0.935		50.6
Boring: U-2	M	3.5837	0.1089	0.935		31.1
Sample: 4	WES I	4.7051	0.1679	0.935		30.3
	WES II	3.9475	0.1513	0.935		11.0
	WES III	3.2451	0.0853	0.935		40.5
Limon, Colo., Site 2**	TP	2.3377	0.0388	0.554	30.0	14.9
Depth: 5.5-7.8 ft	M&M	18.2052	0.5894	0.709		3.3
Boring: U-3	M	15.8503	0.5116	0.662		3.2
Sample: 3	WES I	15.6335	0.5162	0.822		1.4
	WES II	12.4077	0.4178	0.852		0.8
	WES III	5.5403	0.1495	0.685		11.4
Denver, Colo.**	TP	4.5135	0.1713	0.903	17.0	39.9
Depth: 5.7-7.8 ft	M&M	9.9800	0.4879	0.898		48.5
Boring: U-3	M	8.2470	0.3981	0.898		30.2
Sample: 4	WES I	11.8976	0.6141	0.898		28.7
	WES II	10.4287	0.5533	0.898		10.5
	WES III	5.8974	0.2517	0.898		41.5
Newcast[illegible]o., Site 1**	TP	3.4158	0.1446	0.917	13.8	26.3
Depth: [illegible].8 ft	M&M	16.5574	1.1733	0.583		2.3
Boring: [illegible]	M	15.1166	1.0746	0.567		1.9
Sample [illegible]	WES I	15.3451	1.0999	0.633		1.5
	WES II	12.5222	0.9121	0.649		0.9
	WES III	6.3826	0.3770	0.523		15.1
Newcastle, Wyo., Site 2**	TP	3.3093	0.1073	0.889	15.0	50.1
Depth: 6.1-8.3 ft	M&M	5.7157	0.2682	0.932		49.3
Boring: U-2	M	4.7671	0.2188	0.932		30.6
Sample: 4	WES I	6.5303	0.3375	0.932		29.4
	WES II	5.5922	0.3042	0.932		10.7
	WES III	4.1778	0.1720	0.932		39.6

(Continued)

** Data included in correlations between thermocouple psychrometer and filter paper methods.

(Sheet 2 of 3)

Table 5 (Concluded)

Sampling Site	Calibration Curve	Characterization Parameters: Ordinate Intercept A	Slope B	Coefficient of Determination r^2	Initial Conditions: Water Content percent	Soil Suction tsf
Billings, Mont.**	TP	2.4384	0.0743	0.644	14.5	23.0
Depth: 6.7-9.2 ft	M&M	14.0152	0.9136	0.774		5.9
Boring: U-2	M	12.9707	0.8477	0.748		4.8
Sample: 4	WES I	12.3750	0.6711	0.851		2.9
	WES II	9.8941	0.2462	0.876		1.5
	WES III	4.7846		0.874		16.4
Reliance, S. D.**	TP	3.6686	0.0654	0.860	33.2	31.4
Depth: 8.0-10.6 ft	M&M	12.9098	0.3693	0.575		4.5
Boring: U-1	M	11.5253	0.3308	0.545		3.5
Sample: 5	WES I	12.7310	0.3701	0.666		2.8
	WES II	10.5812	0.3137	0.695		1.5
	WES III	4.9572	0.1090	0.873		21.8
Flagstaff, Ariz., Sta 672**	TP	2.5637	0.1178	0.644	6.2	68.1
Depth: 8.4-9.8 ft	M&M	5.9641	0.6564	0.967		78.4
Boring: U-1	M	5.2072	0.5738	0.973		44.6
Sample: 8	WES I	6.0523	0.6985	0.925		52.7
	WES II	4.9299	0.5905	0.924		18.6
	WES III	3.9648	0.3582	0.924		55.5
Flagstaff, Ariz., Sta 861**	TP	2.0336	0.0619	0.586	10.8	23.2
Depth: 11.7-13.7 ft	M&M	6.0542	0.4312	0.634		25.0
Boring: U-3	M	5.3621	0.3819	0.593		17.3
Sample: 7	WES I	5.9315	0.4461	0.737		13.0
	WES II	4.8377	0.3817	0.763		5.2
	WES III	3.6693	0.2033	0.755		29.8
Lackland AFB, Tex.	TP	1.3348	0.0131	0.093	20.0	11.8
Depth: 5.7-7.3 ft	M&M	3.9628	0.1335	0.783		19.6
Boring: U-3	M	3.3367	0.1089	0.783		14.4
Sample: 3	WES I	4.3241	0.1680	0.783		9.2
	WES II	3.6042	0.1514	0.783		3.8
	WES III	3.3973	0.1020	0.783		22.8
Fort Carson, Colo.**	TP	2.6648	0.1277	0.615	10.5	21.1
Depth: 9.4-10.6 ft	M&M	3.1972	0.1582	0.739		34.4
Boring: C-1	M	2.7119	0.1291	0.739		22.7
Sample: 10	WES I	3.3605	0.1991	0.739		18.6
	WES II	2.7359	0.1794	0.739		7.1
	WES III	2.8338	0.1278	0.739		31.0

** Data included in correlations between thermocouple psychrometer and filter paper methods.

(Sheet 3 of 3)

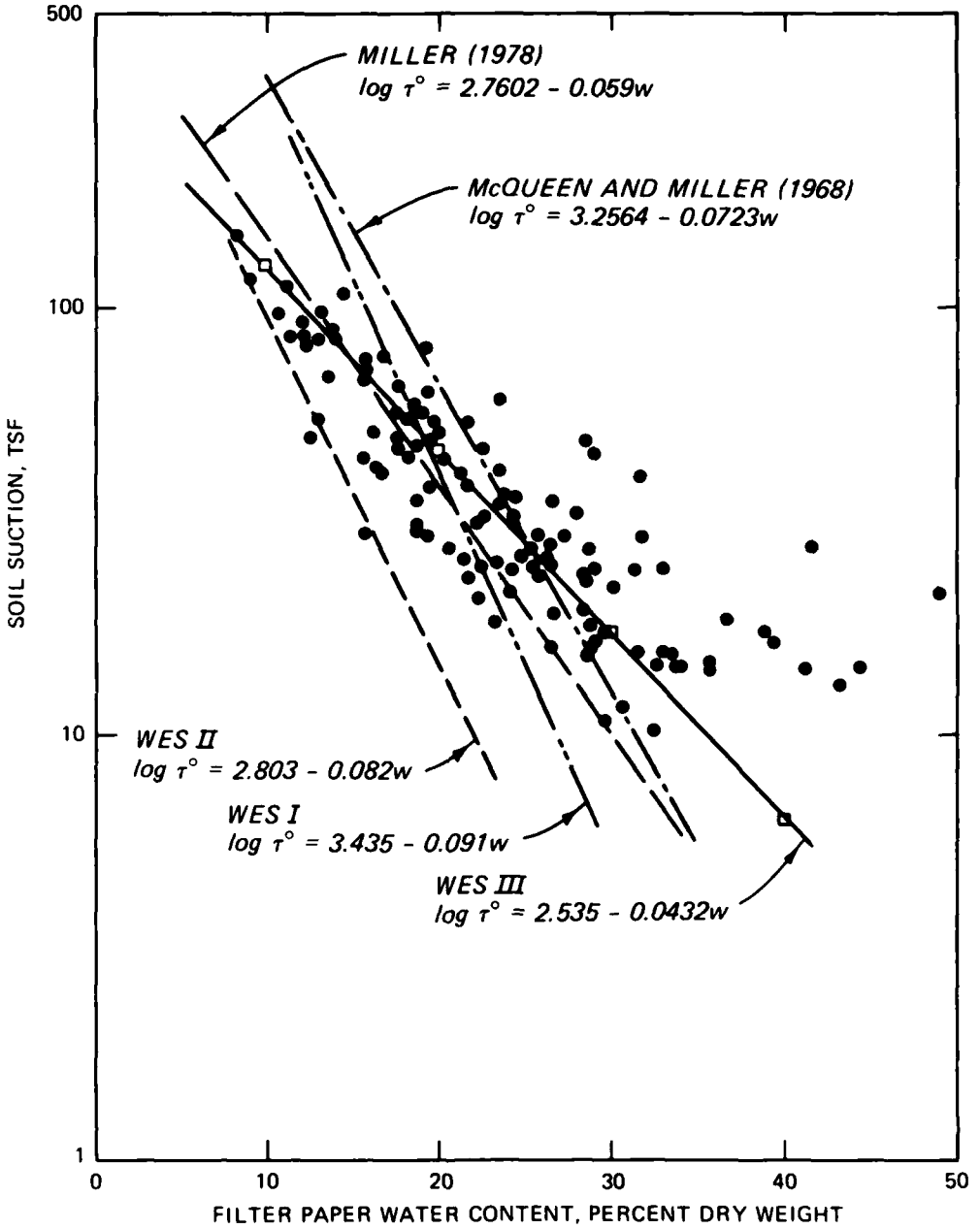

Figure 5. Comparison of WES III with the other filter paper calibration curves; $r^2 = 0.74$ for 122 data points

thermocouple psychrometers to produce larger suctions at low suction levels than the filter paper method. The filter paper method has the advantage of a greater range at both low (<1-tsf) and high (>100-tsf) suctions. Suctions greater than 100 tsf shown for the thermocouple psychrometer method in Appendix B were estimated. The semilog relationship between suction and filter paper water content is used to permit comparison of calibration curves from other sources.

31. Additional factors that reduce the reliability of the analysis include (a) the use of nonidentical specimens in the thermocouple psychrometer and filter paper methods (see paragraph 25) and (b) the tendency of filter paper to become excessively wet when placed into containers with wetted soil specimens (see filter paper water contents in Appendix B). Filter paper specimens wetted in excess of 35 percent water content were not included in the computation of the WES III fitted curve. Sufficient data points were consequently not available to compute a soil suction-water content relationship from the WES III curve for soils from Hattiesburg, Lake Charles, San Antonio, Durant, and Hennessey, as shown in Table 5.

32. The Appendix B data points and Table 5 show that both the thermocouple psychrometer method and the filter paper method may be used to determine the soil suction-water content relationship from which the suction A and B parameters may be evaluated. Correlations were subsequently attempted to determine any relationships between the two methods.

Correlations with Soil Classification Data

33. The results of an exploratory statistical analysis of possible linear relationships of grain size and Atterberg limits with the soil suction parameters indicate that the coefficient of determination r^2 will be less than 0.4 in all cases for both methods. Figure 6 shows an example correlation of the B parameter using the Miller (1978) calibration curve with the plasticity index. A correlation of the B parameter from the thermocouple psychrometer test data with the liquid

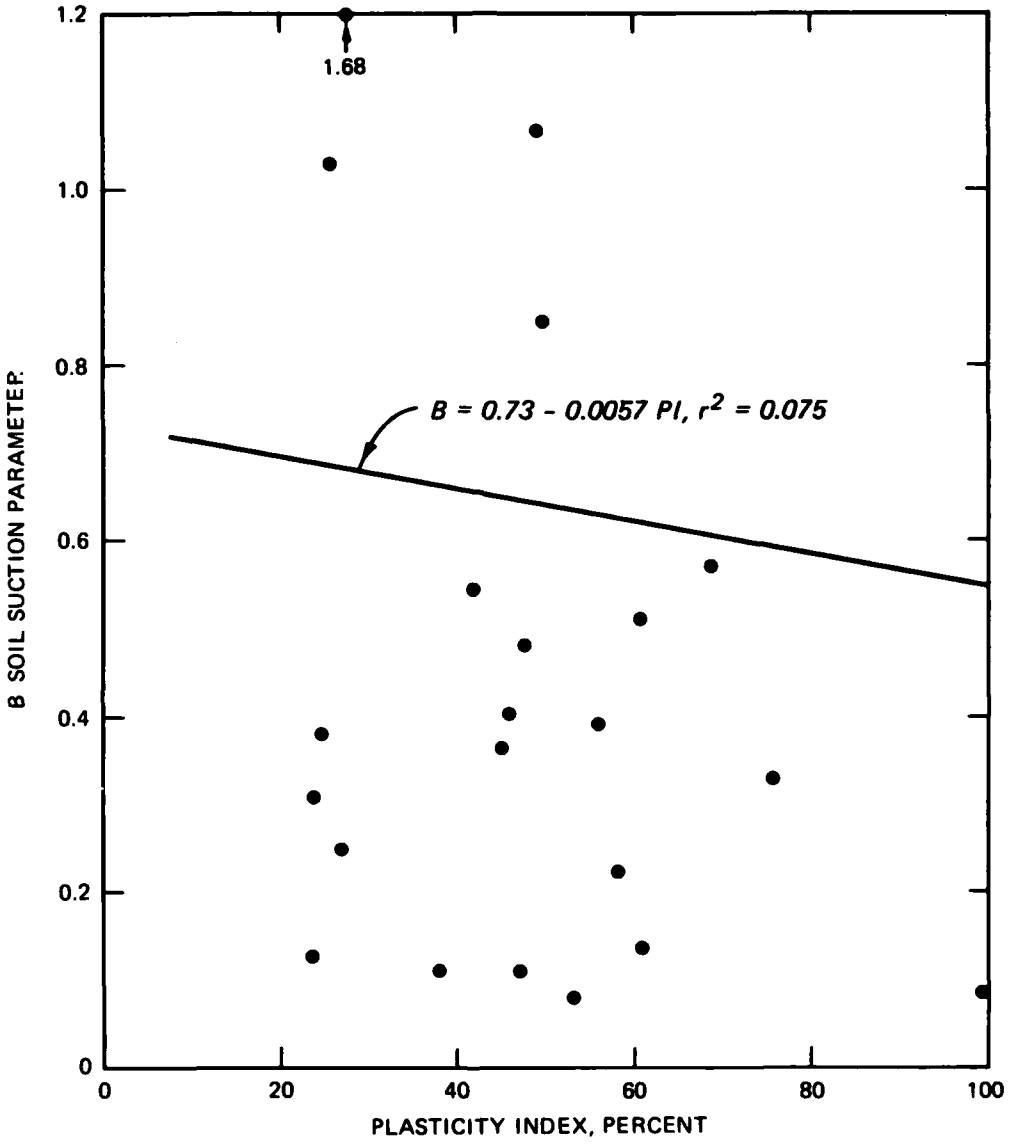

Figure 6. Relationship between plasticity index and B parameter using the Miller (1978) calibration curve of the filter paper method

limit provided the largest r^2 (0.398), whereas most r^2 values were about 0.07. A significant linear correlation does not therefore appear to exist between the soil classification test data and the soil suction A and B parameters. Other nonlinear correlations did not appear promising and were not attempted.

Correlations Between Thermocouple Psychrometer and Filter Paper Methods

34. A study of Table 5 indicates that a sufficient number of data points and/or a sufficient range of suctions were not obtained for some soils. The number of soils with r^2 less than 0.5 is seven using the thermocouple psychrometer method and two using the filter paper method. An r^2 less than 0.5 is assumed to indicate a useless fit of the data. The r^2 values of the following eight soils are less than 0.5 for both the thermocouple psychrometer method and the filter paper method and were not included in subsequent analyses: Jackson, Hattiesburg, Monroe, Lake Charles, San Antonio, Durant, Hennessey, and Lackland AFB. The 16 soils marked by the asterisk (*) in Table 5 were used in the following analyses.

Magnitudes of suction papameters

35. The filter paper method results in soil suction A and B parameters higher than those of the thermocouple psychrometer method with all filter paper calibration curves for 14 of the 16 soils (Table 6). The Miller calibration results in slightly smaller A and B parameters for the soil from Hayes. The WES III fitted curve results in slightly smaller A and B parameters for soils from Hayes and Limon Site 1 (Table 5). These differences in suction parameters A and B can be attributed to errors in the thermocouple psychrometer calibration curves and insensitivity at low suctions, the tendency for filter paper to become too wet when placed in containers with wetted soil specimens, and the use of nonidentical specimens in the two methods. (Note in Appendix A that the filter paper was placed on top of the specimen.) Because the B parameter is inversely related to the swell potential, these observations may explain why predictions of heave using soil suction data from thermocouple psychrometers tend to overpredict the tendency to heave (Johnson 1978, Johnson and Snethen 1978). It is therefore probable that the filter paper method will lead to lower predictions of heave in many cases.

36. Comparison of B parameters shows that B using the WES III

Table 6

Comparison of Thermocouple Psychrometer and Filter Paper Methods

Comparison	Description
Magnitudes of soil suction parameters	Filter paper A and B soil suction parameters exceeded thermocouple psychrometer A and B parameters for 14 of 16 soils for all filter paper calibration curves. The Miller A and B parameters were slightly lower for Hayes. The WES III A and B parameters were slightly lower for Hayes and Limon Site 1
	Filter paper B parameter came within 50 percent and closest to the thermocouple psychrometer B parameter for WES III: 7 of 16 soils Miller: 1 of 16 soils McQueen and Miller: 0 WES I: 0 WES II: 0
	Filter paper B parameter came within 50 percent of the thermocouple psychrometer B parameter for WES III: 8 of 16 soils Miller: 5 of 16 soils McQueen and Miller: 4 of 16 soils WES I: 2 of 16 soils WES II: 2 of 16 soils
	Filter paper A parameter came within 50 percent and closest to the thermocouple psychrometer A parameter for WES III: 12 of 16 soils Miller: 3 of 16 soils McQueen and Miller: 0 WES I: 0 WES II: 0
	Filter paper A parameter came within 50 percent of the thermocouple psychrometer A parameter for WES III: 13 of 16 soils Miller: 5 of 16 soils McQueen and Miller: 4 of 16 soils WES II: 4 of 16 soils WES I: 3 of 16 soils
Magnitude of soil suction at identical initial water content	Filter paper suction came within 50 percent and closest to the thermocouple psychrometer suction for WES III: 6 of 16 soils McQueen and Miller: 5 of 16 soils Miller: 4 of 16 soils WES I: 0 WES II: 0
	Filter paper suction came within 50 percent of the thermocouple psychrometer suction for WES III: 16 of 16 soils Miller: 11 of 16 soils McQueen and Miller: 7 of 16 soils WES I: 7 of 16 soils WES II: 1 of 16 soils

curve is within 50 percent of B from the thermocouple psychrometer method and closer than the other filter paper calibrations for 7 out of 16 soils, while the Miller method comes closer one time (Table 6). The WES III B parameter comes within 50 percent of the thermocouple psychrometer B for 8 of 16 soils, while the Miller curve comes within 50 percent for 5 of 16 soils.

37. Comparison of A parameters shows that the filter paper A using the WES III curve is within 50 percent of the thermocouple psychrometer A and closer than the other filter paper calibrations for 12 of 16 soils, while the Miller A parameter comes closer for 3 of 16 soils. The WES III A parameter is within 50 percent of the thermocouple psychrometer A for 13 of 16 soils, while the Miller A parameter is within 50 percent for 5 of 16 soils.

Soil suction at identical initial water content

38. The soil suctions at identical initial water contents from the filter paper method are either greater or less than the thermocouple suctions, depending on the individual filter paper calibration curve (Table 5). The McQueen and Miller (1968) calibrations usually provide the highest suctions, while the WES II curve provides the lowest suctions, as expected from Figures 4 and 5.

39. The WES III, McQueen and Miller, and Miller curves provide soil suctions within 50 percent and closest to the thermocouple psychrometer suctions for 6, 5, and 4 of 16 soils, respectively (Table 6). The WES III, Miller, McQueen and Miller, WES I, and WES II curves come within 50 percent of the thermocouple psychrometer suctions for 16, 11, 7, 7, and 1 of 16 soils, respectively.

PART IV: CONCLUSIONS AND RECOMMENDATIONS

40. The reliability of the filter paper method appears at least as good as the thermocouple psychrometer method using equipment developed for this study. The number of data points available for each soil did not permit a definite judgment as to the relative reliability between the thermocouple psychrometer method and the filter paper method. The filter paper method has a distinct advantage of greater range at both low (<1-tsf) and high (>100-tsf) suctions.

41. The soil suction parameters from the filter paper method were usually larger than those from the thermocouple psychrometer method. Because the swelling capability is inversely proportional to the B suction parameter, the filter paper method will indicate smaller swell potentials for most of the soils tested during this study.

42. The calibration curves of the filter paper method strongly depend on the testing procedure and time interval following removal of the filter paper from the drying oven prior to weighing. Variations in time interval between 5 seconds and 15 minutes can cause considerable change in the calibration curve (the difference between the McQueen and Miller and WES II curves) and significantly reduce the reproducibility of the filter paper method if a strict testing procedure is not carefully followed. The WES III (fitted) and Miller calibration curves provided the best comparison of data with the thermocouple psychrometer method.

43. A recommended testing procedure for the filter paper method is the same as that described in Appendix A except that (a) the filter paper should be placed at the side of and not in contact with the specimen and (b) at least 15 minutes should be allowed before weighing following removal from the oven. The author (Johnson 1980) has found that the WES II curve is most applicable and satisfactory provided that a time interval of at least 15 minutes is allowed before weighing following removal from the oven. Adherance to a 5-second time interval such as required for the McQueen and Miller calibration curve is difficult, particularly if many soil specimens are to be tested and the

drying oven cannot be located close to the gravimetric scale.

44. The Teflon containers of the thermocouple psychrometer equipment developed for this study should be replaced with metal containers and the calibration tests repeated to determine if reproducibility at low suctions can be improved.

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APPENDIX A: FILTER PAPER METHOD FOR DETERMINING SOIL SUCTION

Developing the Calibration Curve

1. The calibration curve is developed as follows:

   a. Place two pieces of filter paper in the bottom of a self-sealing plastic container (i.e., in opposite corners).

   b. Place a No. 10 rubber stopper in the middle of the bottom of the plastic container, and saturate the pieces of filter paper with approximately 3 ml of WES NaCl calibration standard solution (290 moles/kg).

   c. Place a single sheet of pentachlorophenol-treated filter paper on top of the rubber stopper, and seal the container. Allow the filter paper to equilibrate at a relatively constant temperature for 1 week. (Absolute temperature control is less important than minimizing temperature fluctuations.)

   d. Remove the pentachlorophenol-treated filter paper, and within 15 minutes determine its wet weight to the nearest 0.001 g. Dry the filter paper at 110°C for 24 hours, and determine its dry weight to the nearest 0.001 g within 15 minutes following removal from the oven. Calculate the water content of the sheet, and plot it versus the log of the soil suction* for the standard solution concentration.

   e. Repeat steps a-d with standard solution concentrations of 500, 1000, and 1800 moles/kg. The resulting set of points is the calibration curve (i.e., water content versus log of soil suction).

Testing Procedure

2. The testing procedure is as follows:

   a. From either an undisturbed or a compacted soil sample, obtain 10 representative specimens with approximate dimensions of 1-1/2 by 1-1/2 in. (Exact size is not as

---

* Soil suction can be determined from standard solution concentration as follows:

$$\frac{\text{concentration, moles/kg}}{39.85} = \text{soil suction, bars}$$

$$\text{soil suction, bars} \times 1.044 = \text{soil suction, tsf}$$

important as having the 10 specimens as nearly the same size as possible.)

b. Place each specimen in a self-sealing plastic container.

(1) Take two of the containers (specimens at their natural water content); place a sheet of pentachlorophenol-treated filter paper on top of both specimens; and seal the containers.

(2) Depending on the natural water content, dry a portion of the remaining specimens at room temperature for varying lengths of time, and add varying amounts of distilled water to the other portion of the remaining specimens. As the individual drying or wetting is completed, place a single sheet of pentachlorophenol-treated filter paper on top of the specimen, and seal the container. Take care when wetting not to wet the side of the specimen on which the filter paper will rest.

c. Allow the sheets of filter paper to equilibrate for approximately 1 week in a room with a temperature of approximately 70°F and minimal temperature variation.

d. Remove the sheets of filter paper, and determine within 15 minutes their wet weight to the nearest 0.001 g. Dry the sheets of filter paper at 110°C for 24 hours, and determine their dry weight to the nearest 0.001 g within 15 minutes following removal from the oven. Calculate the water content of the sheets of filter paper, and convert the water content to soil suction using the previously developed calibration curve.

e. Determine the water content of each soil specimen, and plot it versus the log of the soil suction determined for the corresponding sheet of filter paper. The resulting curve is the soil suction-water content relationship for the soil sample and has the form

$$\log \tau^{\circ} = A - Bw$$

where

τ° = soil suction, tsf

A and B = intercept and slope of curve, respectively

w = water content, percent

APPENDIX B:

SOIL SUCTION-WATER CONTENT RELATIONSHIPS

- TABLE 1 - SOIL SUCTION AND WATER CONTENT DATA USING THERMOCOUPLE PSYCHROMETER

SITE: JACKSON, MS
BOR: U-2 SAM: 4 DEP: 7.2-9.4 FT

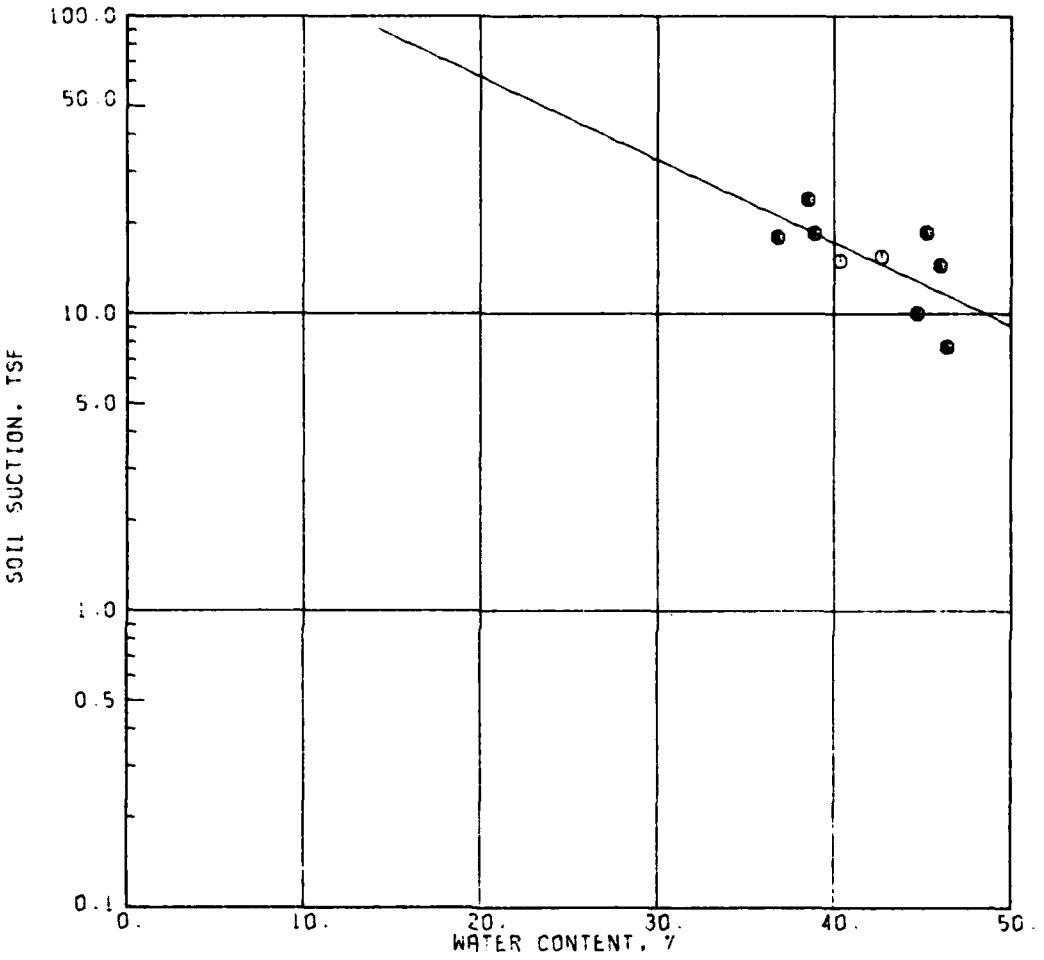
SPECIMEN NUMBER	SOIL SUCTION, TSF	WATER CONTENT %
1	15.5	42.7
2	15.0	40.3
3	18.7	45.2
4	10.0	44.7
5	14.5	46.0
6	7.7	46.4
7	18.1	36.3
8	18.6	38.9
9	24.2	38.5

LOG SOIL SUCTION = 2.3514 -0.0278 * WC

- TABLE 2 - SOIL SUCTION AND WATER CONTENT DATA USING FILTER PAPER AND CALIBRATION CURVES

SITE: JACKSON, MS
BOR: U-2 SAM: 4 DEP: 7.2-9.4 FT

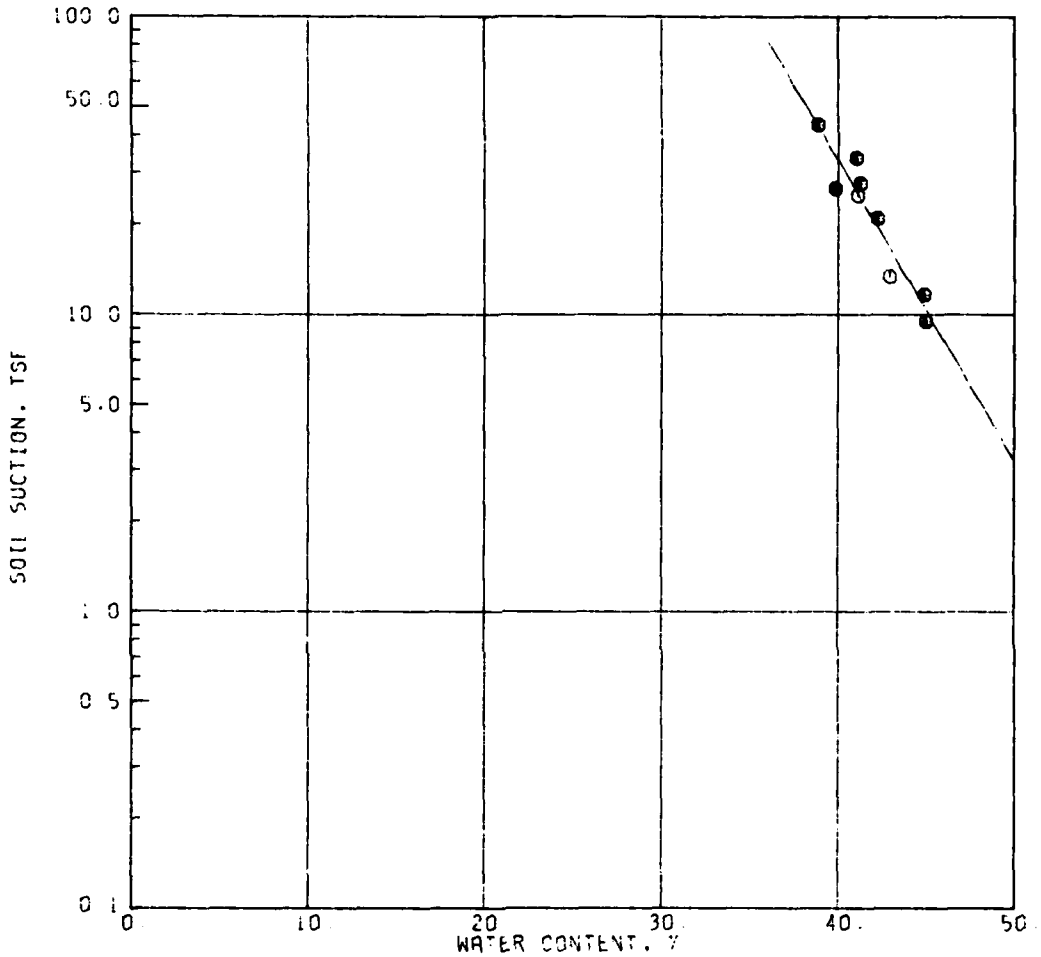
SPECIMEN NUMBER	MOISTURE CONTENT FILTER PAPER %	- - - SOIL SUCTION, TSF - - - McQUEEN/ MILLER 1968	MILLER 1978	W.E.S. I 1979	W.E.S. II 1979	SOIL WATER CONTENT %
1	29.44	13.4	10.6	5.7	2.4	42.93
2	25.68	25.1	17.6	12.5	5.0	41.12
3	23.92	33.6	22.3	18.1	6.9	41.02
4	26.73	21.1	15.2	10.1	4.1	42.22
5	31.51	9.5	8.0	3.7	1.7	44.99
6	30.29	11.7	9.4	4.8	2.1	44.89
7	25.35	26.5	18.4	13.4	5.3	39.85
8	25.12	27.6	19.0	14.1	5.5	41.27
9	22.38	43.5	27.5	25.0	9.3	38.87



SOIL SUCTION VERSUS WATER CONTENT RELATIONSHIP USING THERMOCOUPLE PSYCHROMETERS

LOG SOIL SUCTION = 2.3514 -0.0278 * WATER CONTENT

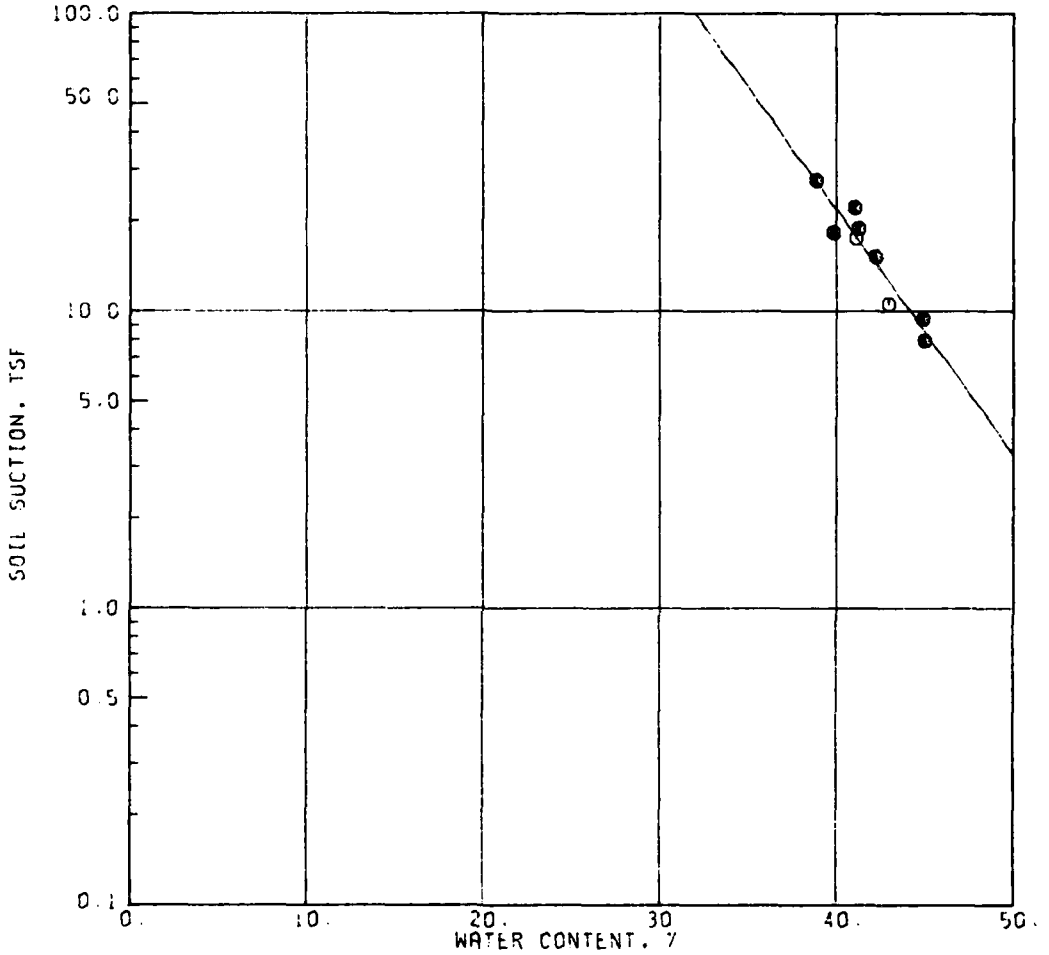
SITE: JACKSON, MS
BOR: U-2 SAM: 4 DEP: 7.2-



SOIL SUCTION VERSUS WATER CONTENT RELATIONSHIP USING FILTER PAPER & MCQUEEN/MILLER '68 CALIBRATION CURVE

LOG SOIL SUCTION = 5.5437 -0.1007 * WATER CONTENT

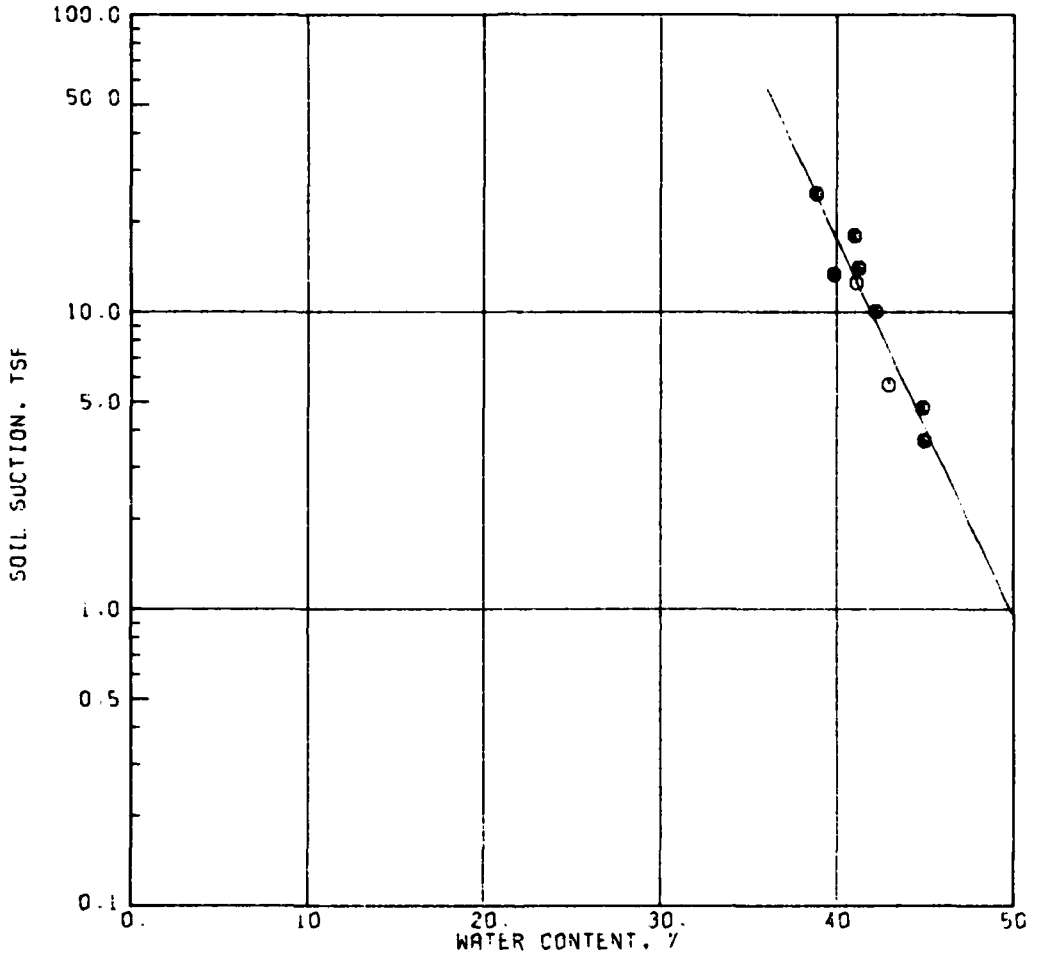
SITE: JACKSON, MS
BOR: U-2 SAM: 4 DEP: 7.2-



SOIL SUCTION VERSUS WATER CONTENT RELATIONSHIP USING FILTER PAPER & MILLER '78 CALIBRATION CURVE

LOG SOIL SUCTION = 4.6268 -0.0821 * WATER CONTENT

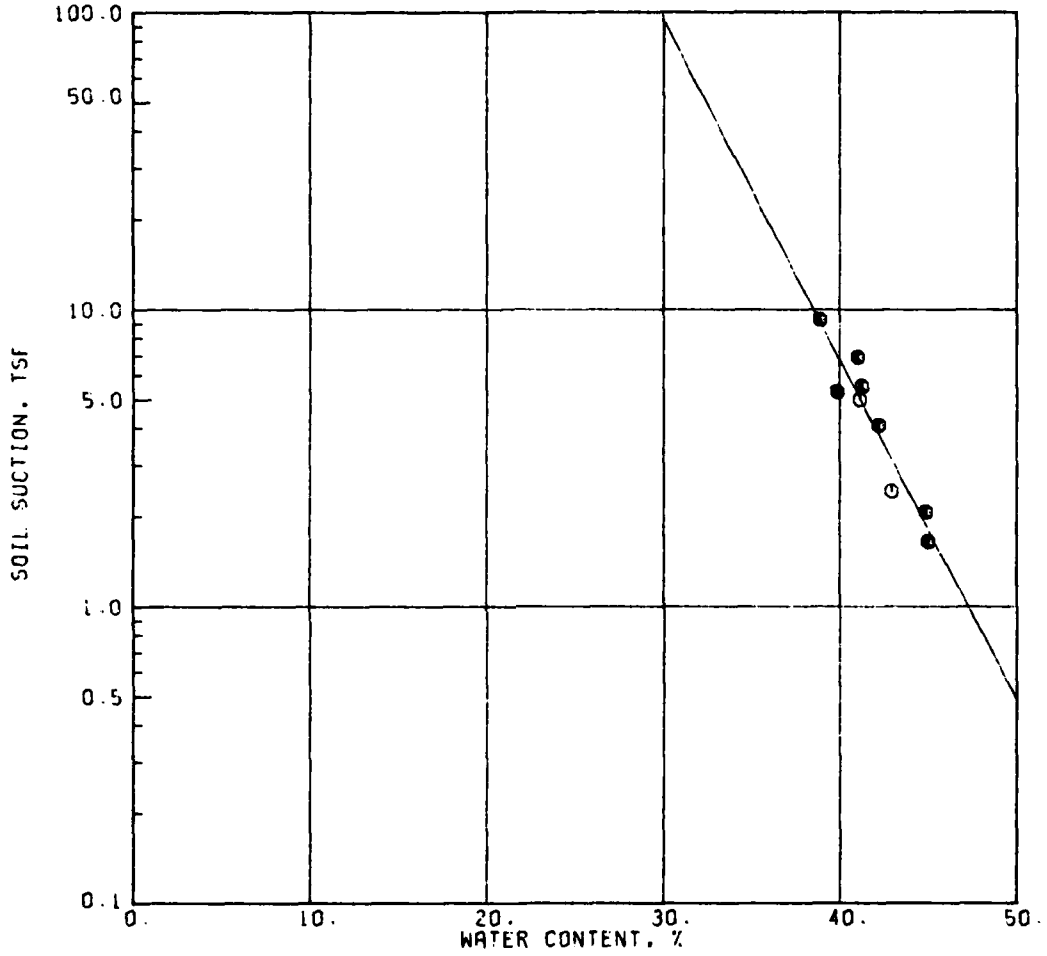
SITE: JACKSON, MS
BOR: U-2 SAM: 4 DEP: 7.2-



SOIL SUCTION VERSUS WATER CONTENT RELATIONSHIP USING FILTER PAPER & W.E.S.-I '79 CALIBRATION CURVE

LOG SOIL SUCTION = 6.3139 -0.1267 * WATER CONTENT

SITE: JACKSON, MS
BOR: U-2 SAM: 4 DEP: 7.2-



SOIL SUCTION VERSUS WATER CONTENT RELATIONSHIP USING FILTER PAPER & W.E.S.-II '79 CALIBRATION CURVE

LOG SOIL SUCTION = 5.3972 -0.1142 * WATER CONTENT

SITE: JACKSON, MS
BOR: U-2 SAM: 4 DEP: 7.2-

- TABLE 1 - SOIL SUCTION AND WATER CONTENT DATA USING THERMOCOUPLE PSYCHROMETER

SITE: HATTIESBURG, MS
BOR: U-2 SAM: 4 DEP: 6.6-7.8 FT

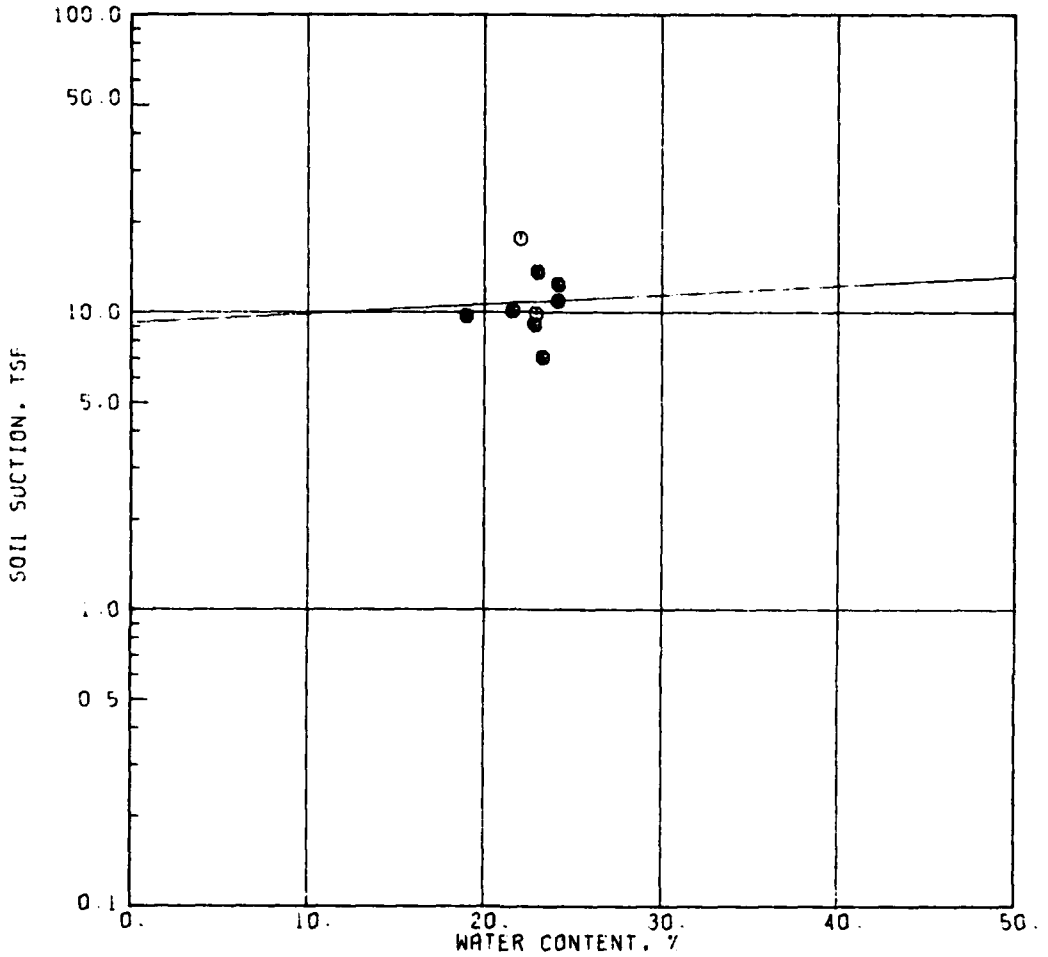
SPECIMEN NUMBER	SOIL SUCTION, TSF	WATER CONTENT %
1	17.7	22.0
2	9.9	22.9
3	7.1	23.3
4	12.5	24.2
5	9.2	22.8
6	11.0	24.1
7	13.7	23.0
8	10.1	21.6
9	9.8	19.0

LOG SOIL SUCTION = 0.9659 0.0031 * WC

- TABLE 2 - SOIL SUCTION AND WATER CONTENT DATA USING FILTER PAPER AND CALIBRATION CURVES

SITE: HATTIESBURG, MS
BOR: U-2 SAM: 4 DEP: 6.6-7.8 FT

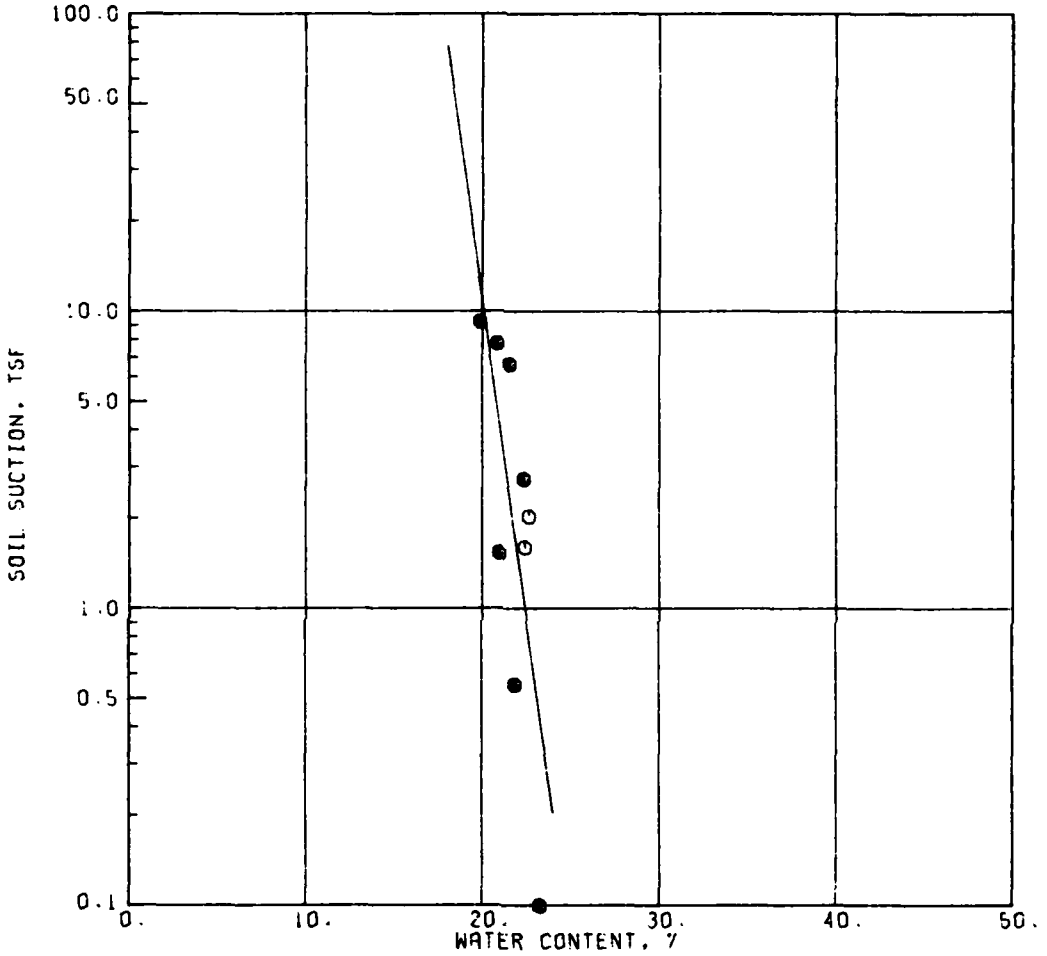
SPECIMEN NUMBER	MOISTURE CONTENT FILTER PAPER %	- - - SOIL SUCTION, TSF - - - McQUEEN/ MILLER 1968	MILLER 1978	W.E.S. I 1979	W.E.S. II 1979	SOIL WATER CONTENT %
1	42.20	1.6	1.9	0.4	0.2	22.40
2	40.76	2.0	2.3	0.5	0.3	22.63
3	42.44	1.5	1.8	0.4	0.2	20.95
4	48.58	0.6	0.8	0.1	0.1	21.86
5	62.98	0.1	0.1	0.1	0.1	23.26
6	39.02	2.7	2.9	0.8	0.4	22.32
7	33.66	6.7	5.9	2.4	1.1	21.55
8	32.69	7.8	6.8	2.9	1.3	20.83
9	31.68	9.2	7.8	3.6	1.6	19.87
10	38.07	3.2	3.3	0.9	0.5	22.02
11	40.00	2.3	2.5	0.6	0.3	20.74
12	38.10	3.2	3.3	0.9	0.5	21.13
13	41.50	1.8	2.0	0.5	0.3	21.18
14	38.16	3.1	3.2	0.9	0.5	23.36
15	40.47	2.1	2.4	0.6	0.3	23.02



SOIL SUCTION VERSUS WATER CONTENT RELATIONSHIP USING THERMOCOUPLE PSYCHROMETERS

LOG SOIL SUCTION = 0.9659 0.0031 * WATER CONTENT

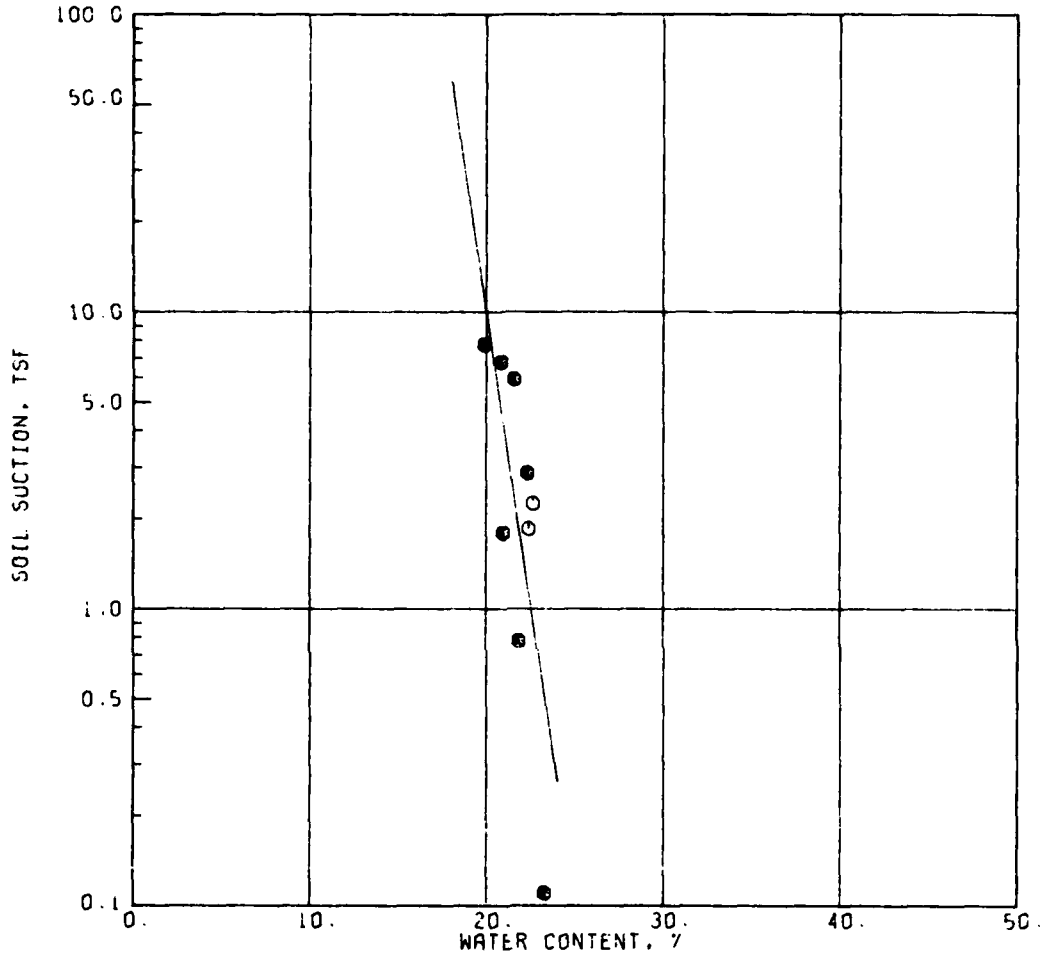
SITE: HATTIESBURG, MS
BOR: U-2 SAM: 4 DEP: 6.6-



SOIL SUCTION VERSUS WATER CONTENT RELATIONSHIP USING FILTER PAPER & MCQUEEN/MILLER '68 CALIBRATION CURVE

LOG SOIL SUCTION = 9.6448 -0.4305 * WATER CONTENT

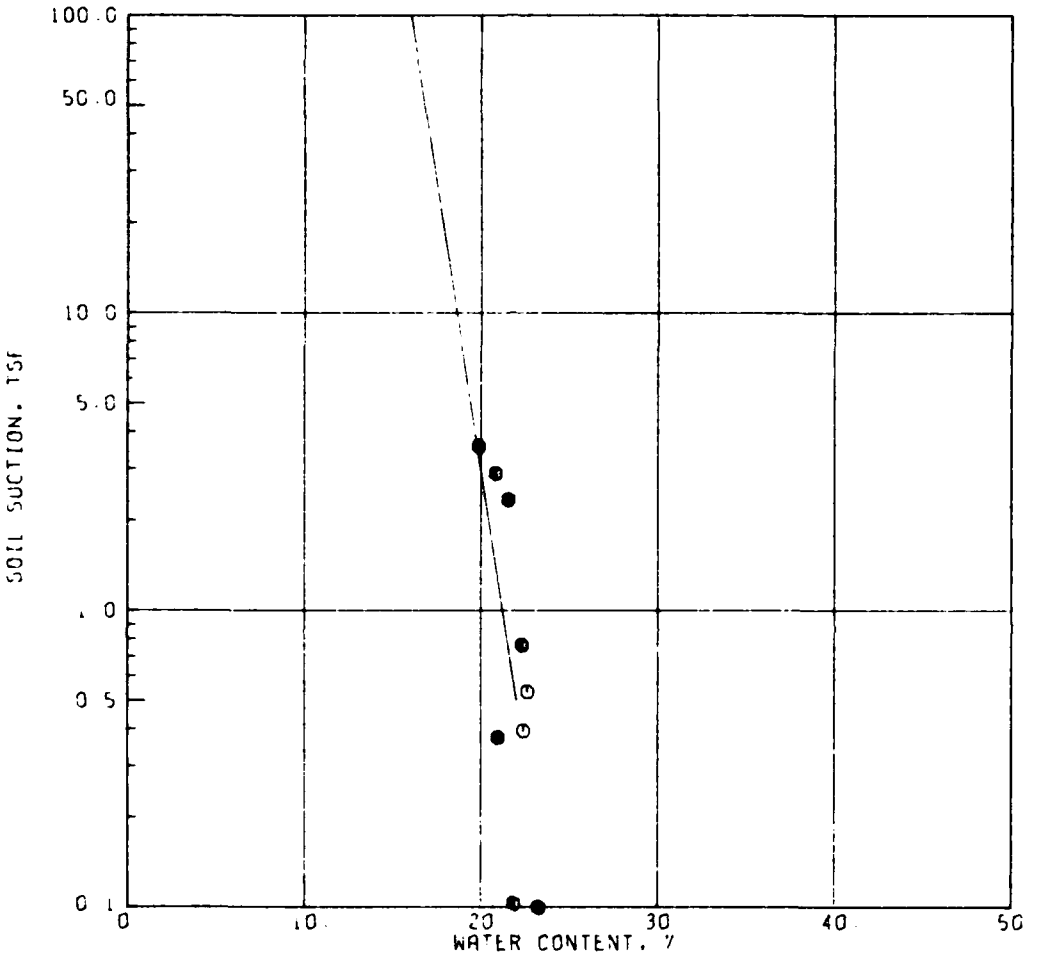
SITE: HATTIESBURG, MS
BOR: U-2 SAM: 4 DEP: 6.6-



SOIL SUCTION VERSUS WATER CONTENT RELATIONSHIP USING FILTER PAPER & MILLER '78 CALIBRATION CURVE

LOG SOIL SUCTION = 8.8516 -0.3930 * WATER CONTENT

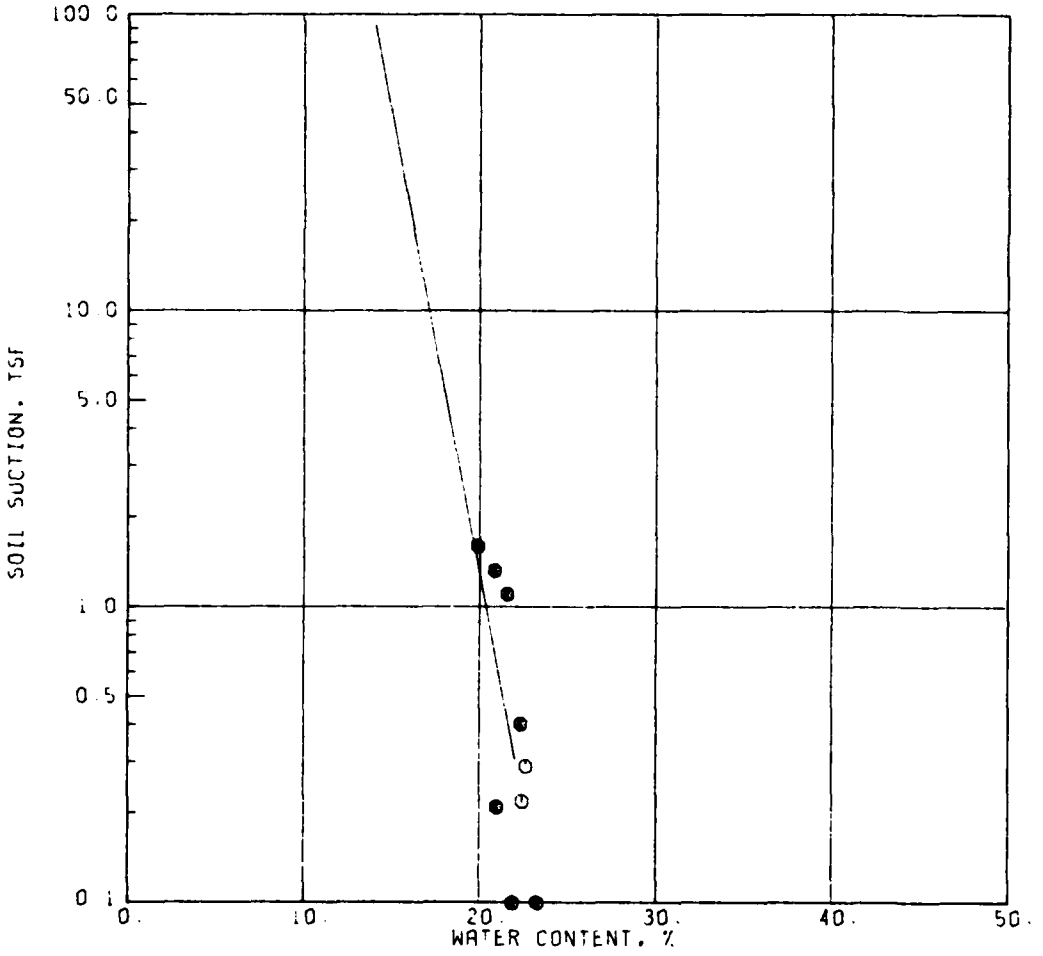
SITE: HATTIESBURG, MS
BOR: U-2 SAM: 4 DEP: 6.6-



SOIL SUCTION VERSUS WATER CONTENT RELATIONSHIP USING FILTER PAPER & W.E.S.-I '79 CALIBRATION CURVE

LOG SOIL SUCTION = 8.1353 -0.3835 * WATER CONTENT

SITE: HATTIESBURG, MS
BOR: U-2 SAM: 4 DEP: 6.6-



SOIL SUCTION VERSUS WATER CONTENT RELATIONSHIP USING FILTER PAPER & W.E.S.-II '79 CALIBRATION CURVE

LOG SOIL SUCTION = 6.3054 -0.3100 * WATER CONTENT

SITE: HATTIESBURG, MS
BOR: U-2 SAM: 4 DEP: 6.6-

- TABLE 1 - SOIL SUCTION AND WATER CONTENT DATA
USING THERMOCOUPLE PSYCHROMETER

SITE: MONROE, LA
BOR: U-1 SAM: 3 DEP: 5.6-7.4 FT

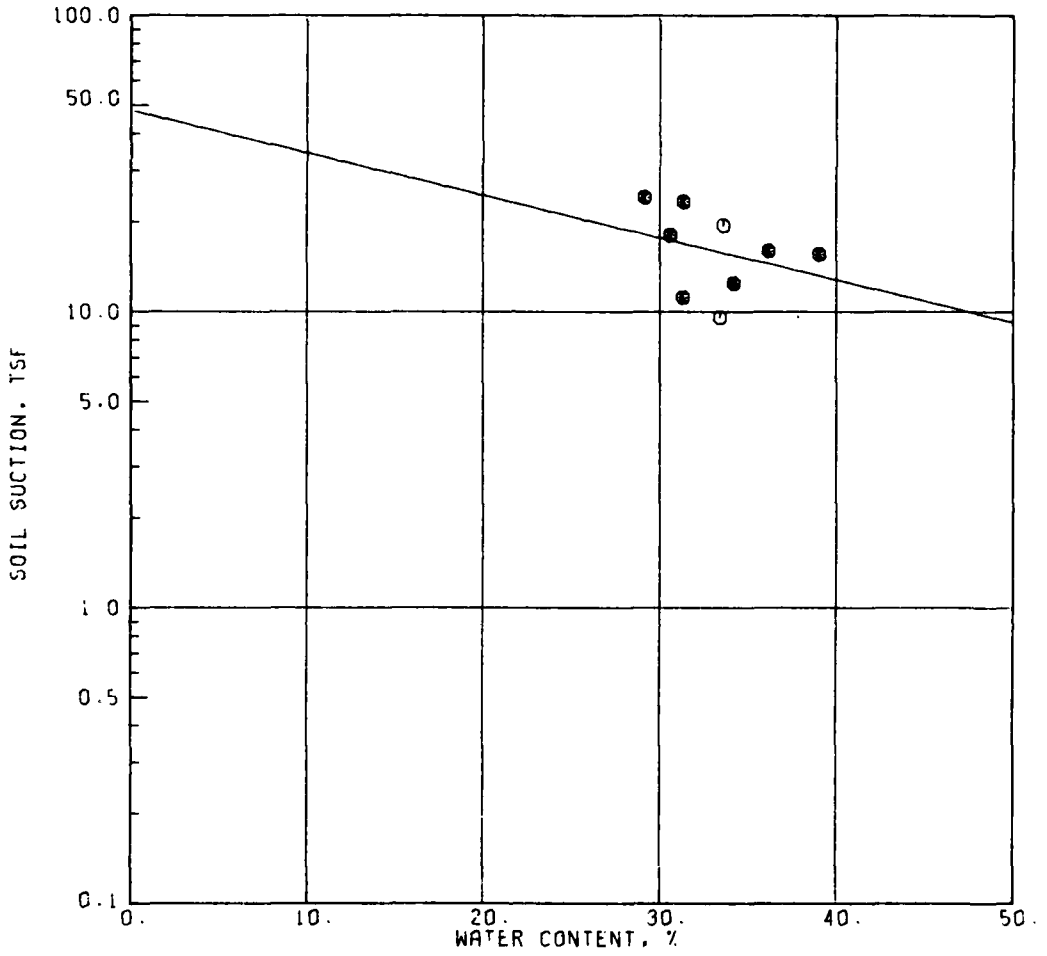
SPECIMEN NUMBER	SOIL SUCTION, TSF	WATER CONTENT, %
1	19.6	33.6
2	9.6	33.4
3	16.0	36.2
4	12.5	34.2
5	15.6	39.0
6	11.2	31.3
7	18.1	30.6
8	24.3	29.2
9	23.5	31.4

LOG SOIL SUCTION = 1.6771 -0.0143 * WC

- TABLE 2 - SOIL SUCTION AND WATER CONTENT DATA
USING FILTER PAPER AND CALIBRATION CURVES

SITE: MONROE, LA
BOR: U-1 SAM: 3 DEP: 5.6-7.4 FT

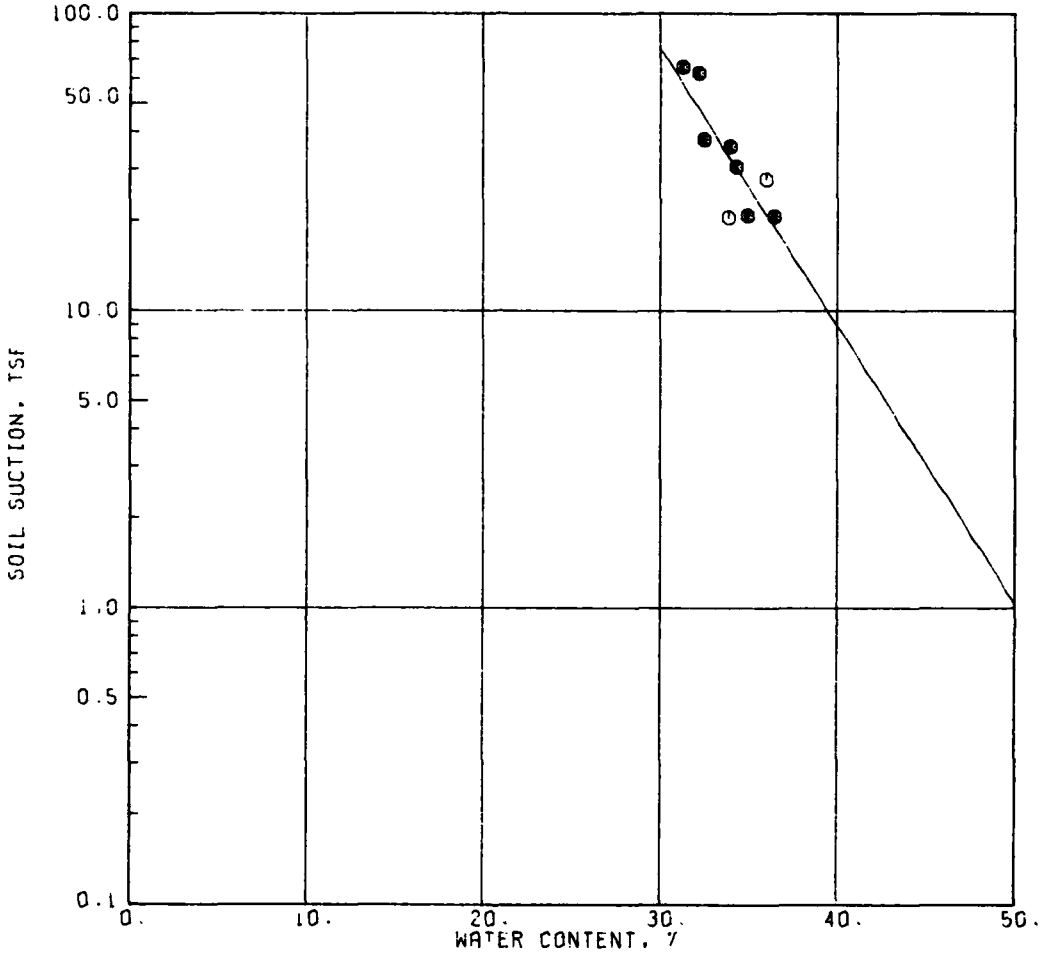
SPECIMEN NUMBER	MOISTURE CONTENT FILTER PAPER %	- - - SOIL SUCTION, TSF - - - McQUEEN/ MILLER 1968	MILLER 1978	W.E.S. I 1979	W.E.S. II 1979	SOIL WATER CONTENT %
1	25.12	27.6	19.0	14.1	5.5	36.00
2	26.89	20.5	14.9	9.7	4.0	33.85
3	24.54	30.4	20.5	15.9	6.2	34.32
4	26.79	20.9	15.1	9.9	4.0	34.92
5	26.85	20.7	15.0	9.8	4.0	36.44
6	23.58	35.6	23.4	19.4	7.4	33.98
7	19.91	65.6	38.5	42.0	14.8	31.27
8	20.18	62.7	37.1	39.7	14.1	32.18
9	23.27	37.5	24.4	20.8	7.9	32.49



SOIL SUCTION VERSUS WATER CONTENT RELATIONSHIP USING THERMOCOUPLE PSYCHROMETERS

LOG SOIL SUCTION = 1.6771 -0.0143 * WATER CONTENT

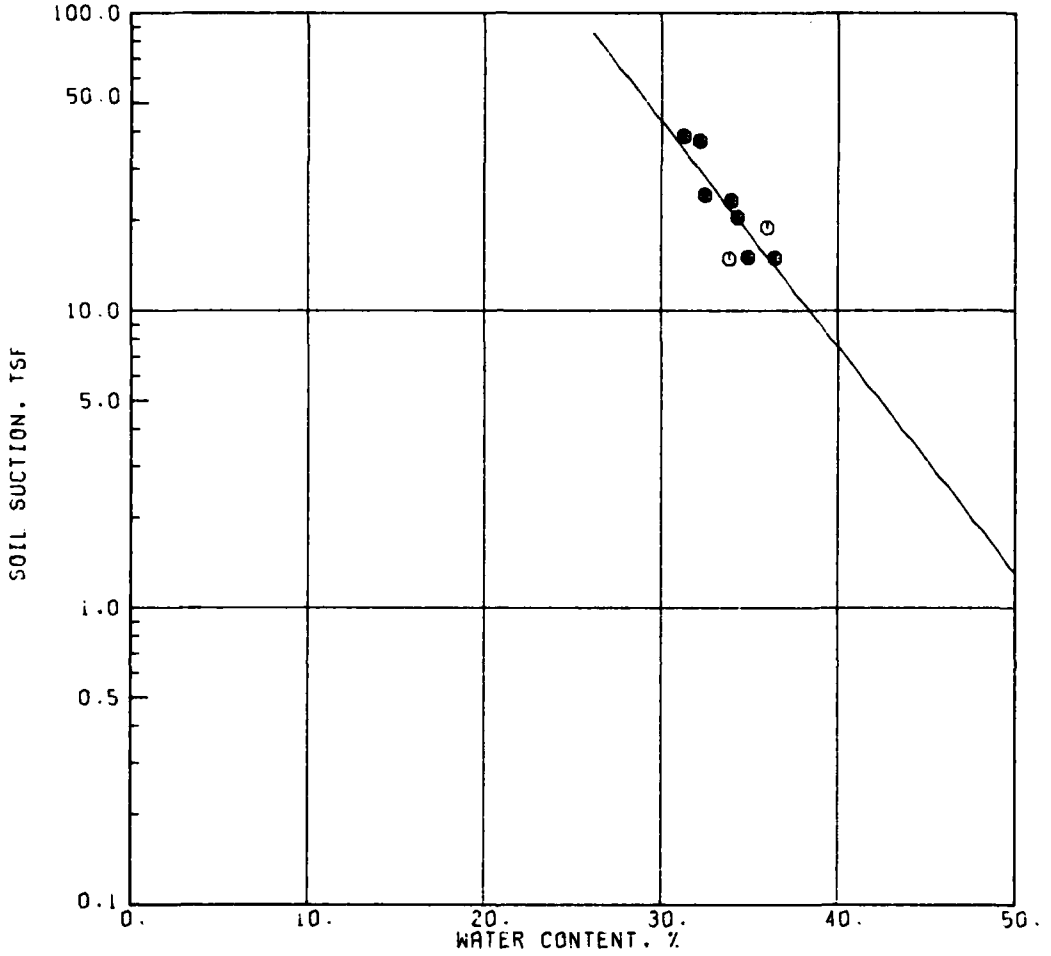
SITE: MONROE, LA
BOR: U-1 SAM: 3 DEP: 5.6-



SOIL SUCTION VERSUS WATER CONTENT RELATIONSHIP USING FILTER PAPER & MCQUEEN/MILLER '68 CALIBRATION CURVE

LOG SOIL SUCTION = 4.6695 -0.0930 * WATER CONTENT

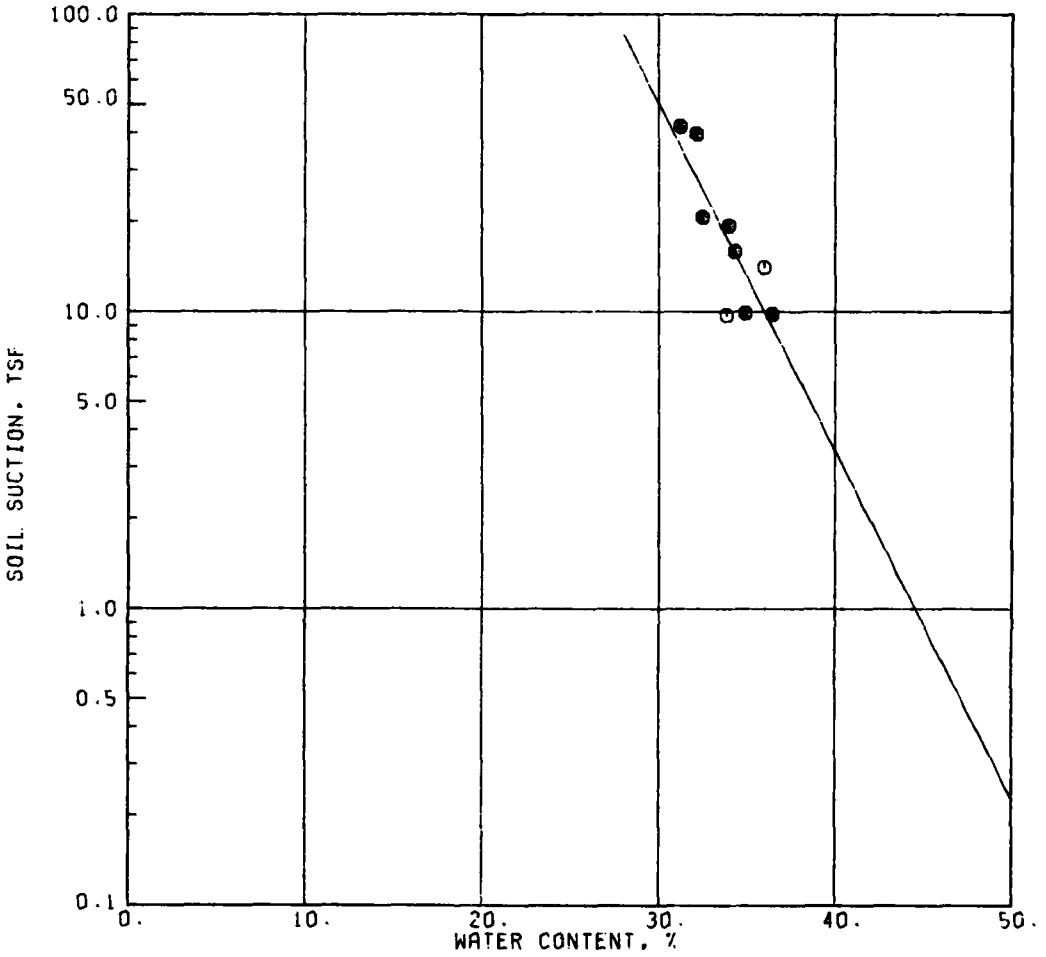
SITE: MONROE, LA
BOR: U-1 SAM: 3 DEP: 5.6-



SOIL SUCTION VERSUS WATER CONTENT RELATIONSHIP USING FILTER PAPER & MILLER '78 CALIBRATION CURVE

LOG SOIL SUCTION = 3.9133 -0.0759 * WATER CONTENT

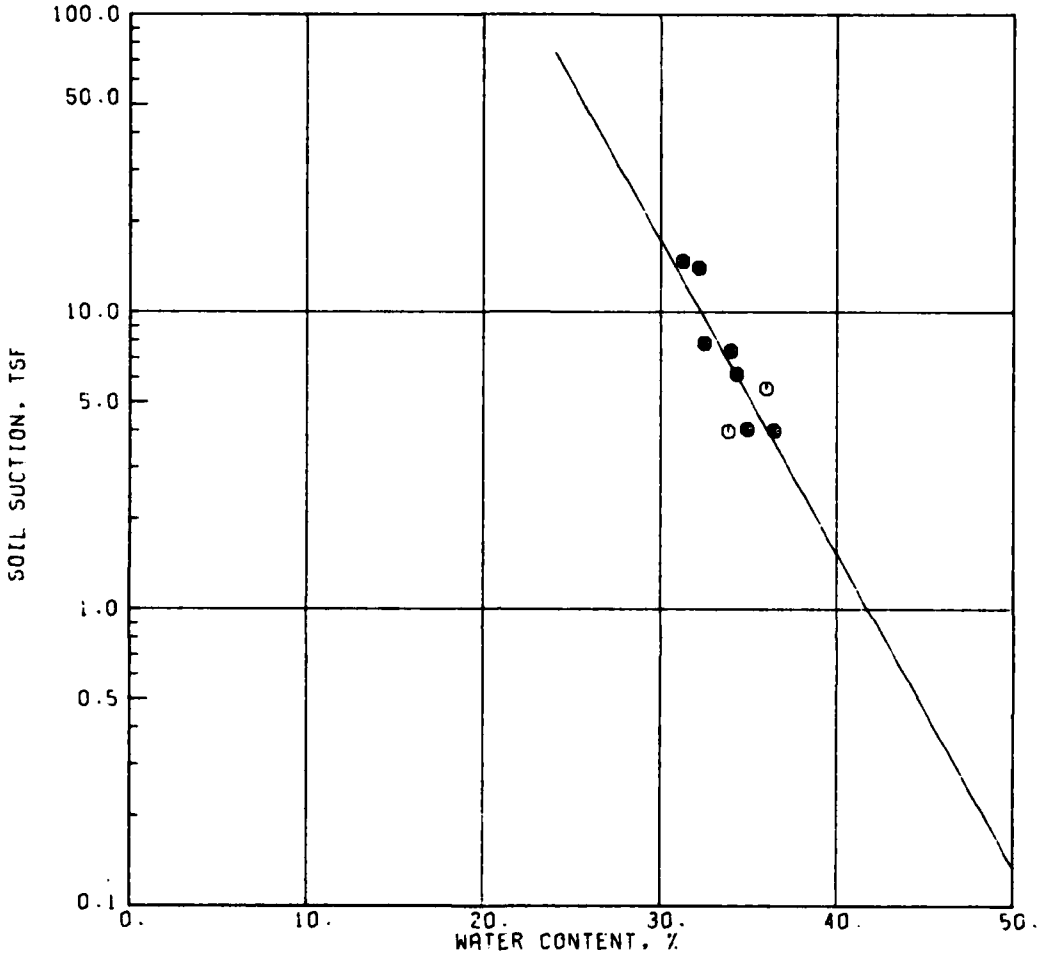
SITE: MONROE, LA
BOR: U-1 SAM: 3 DEP: 5.6-



SOIL SUCTION VERSUS WATER CONTENT RELATIONSHIP USING FILTER PAPER & W.E.S.-I '79 CALIBRATION CURVE

LOG SOIL SUCTION = 5.2136 -0.1171 * WATER CONTENT

SITE: MONROE, LA
BOR: U-1 SAM: 3 DEP: 5.6-



SOIL SUCTION VERSUS WATER CONTENT RELATIONSHIP USING FILTER PAPER & W.E.S.-II '79 CALIBRATION CURVE

LOG SOIL SUCTION = 4.4057 -0.1055 * WATER CONTENT

SITE: MONROE, LA
BOR: U-1 SAM: 3 DEP: 5.6-

- TABLE 1 - SOIL SUCTION AND WATER CONTENT DATA USING THERMOCOUPLE PSYCHROMETER

SITE: LAKE CHARLES, LA
BOR: U-2 SAM: 4 DEP: 6.8-8.9 FT

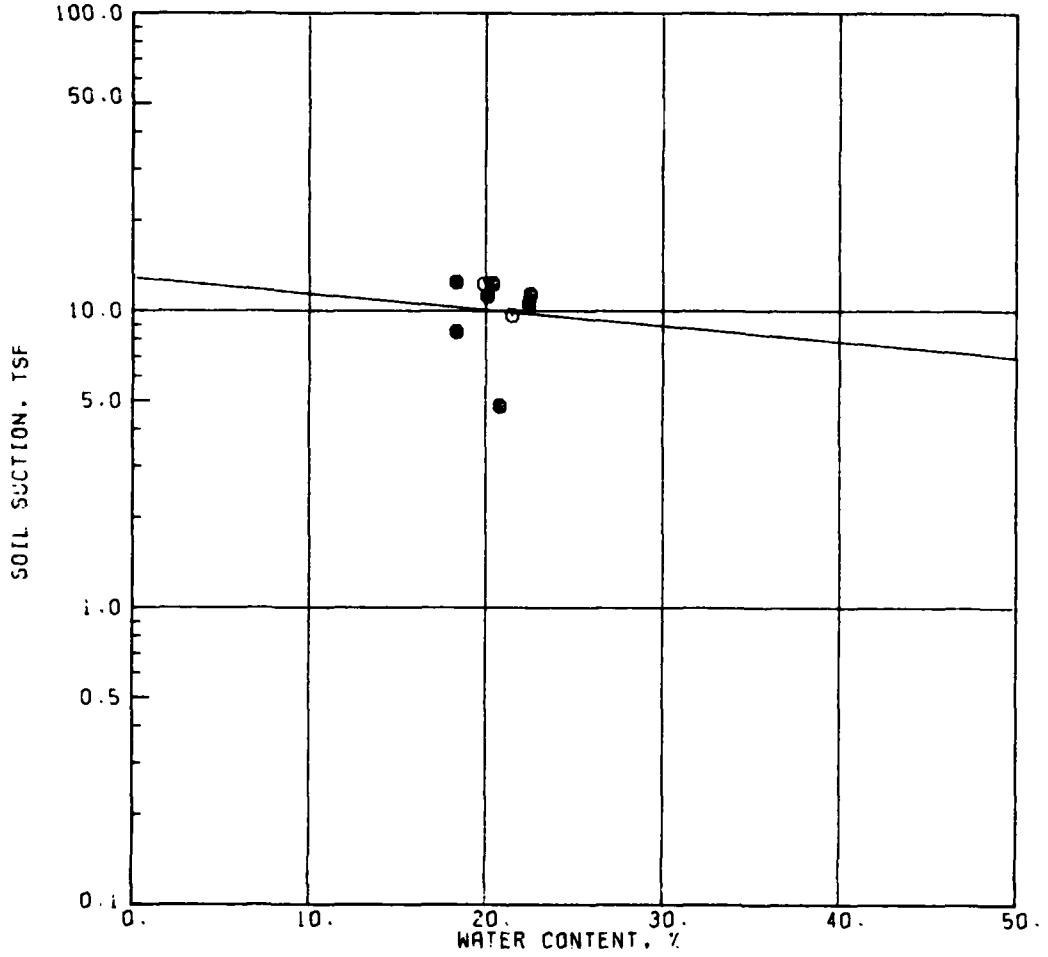
SPECIMEN NUMBER	SOIL SUCTION, TSF	WATER CONTENT %
1	9.6	21.5
2	12.3	19.9
3	12.3	20.4
4	10.6	22.4
5	11.3	22.5
6	4.8	20.8
7	8.5	18.3
8	11.2	20.1
9	12.5	18.3

LOG SOIL SUCTION = 1.1092 -0.0054 * WC

- TABLE 2 - SOIL SUCTION AND WATER CONTENT DATA USING FILTER PAPER AND CALIBRATION CURVES

SITE: LAKE CHARLES, LA
BOR: U-2 SAM: 4 DEP: 6.8-8.9 FT

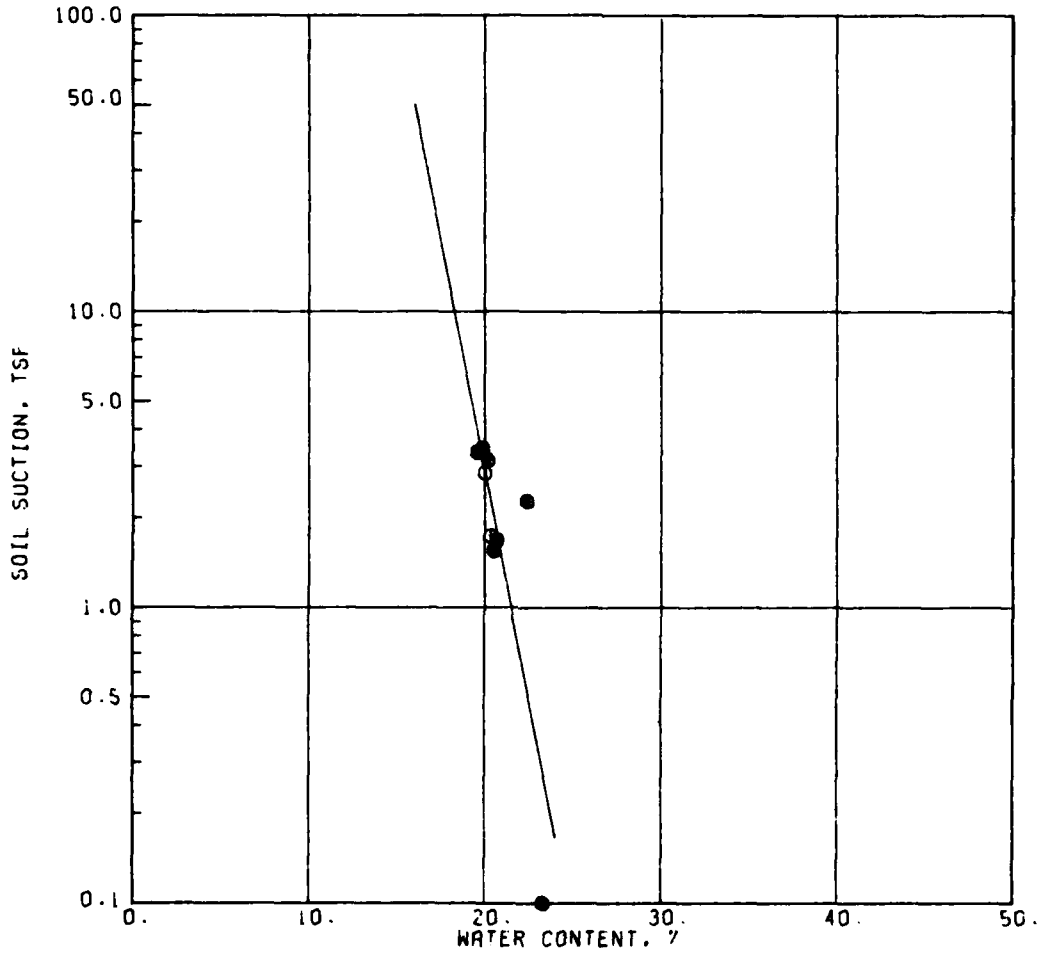
SPECIMEN NUMBER	MOISTURE CONTENT FILTER PAPER %	- - - SOIL SUCTION, TSF - - - McQUEEN/ MILLER 1968	MILLER 1978	W.E.S. I 1979	W.E.S. II 1979	SOIL WATER CONTENT %
1	38.79	2.8	3.0	0.8	0.4	20.02
2	41.70	1.7	2.0	0.4	0.2	20.33
3	41.90	1.7	1.9	0.4	0.2	20.70
4	42.40	1.6	1.8	0.4	0.2	20.53
5	97.14	0.1	0.1	0.1	0.1	23.30
6	40.09	2.3	2.5	0.6	0.3	22.39
7	37.62	3.4	3.5	1.0	0.5	19.87
8	37.80	3.3	3.4	1.0	0.5	19.57
9	38.18	3.1	3.2	0.9	0.5	20.20



SOIL SUCTION VERSUS WATER CONTENT RELATIONSHIP USING THERMOCOUPLE PSYCHROMETERS

LOG SOIL SUCTION = 1.1092 -0.0054 * WATER CONTENT

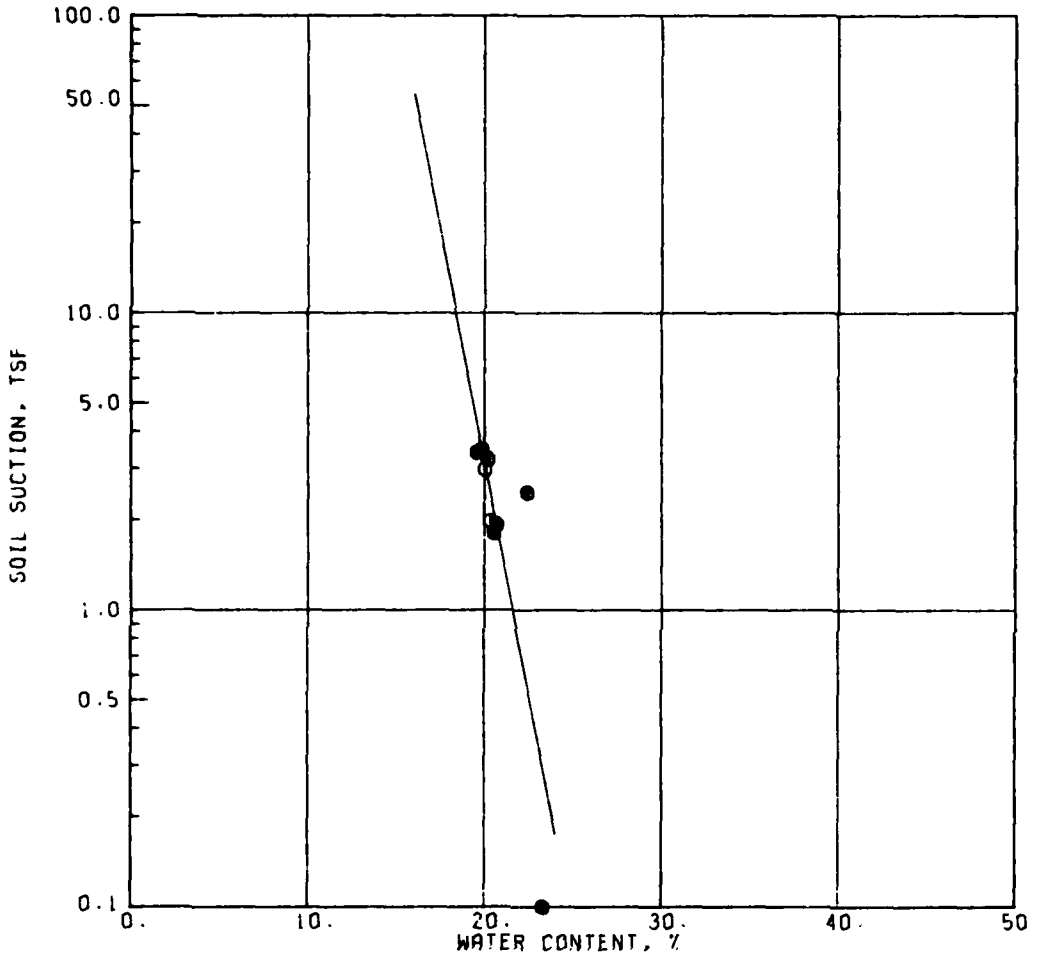
SITE: LAKE CHARLES, LA
BOR: U-2 SAM: 4 DEP: 6.8-



SOIL SUCTION VERSUS WATER CONTENT RELATIONSHIP USING FILTER PAPER & MCQUEEN/MILLER '68 CALIBRATION CURVE

LOG SOIL SUCTION = 6.6682 -0.3103 * WATER CONTENT

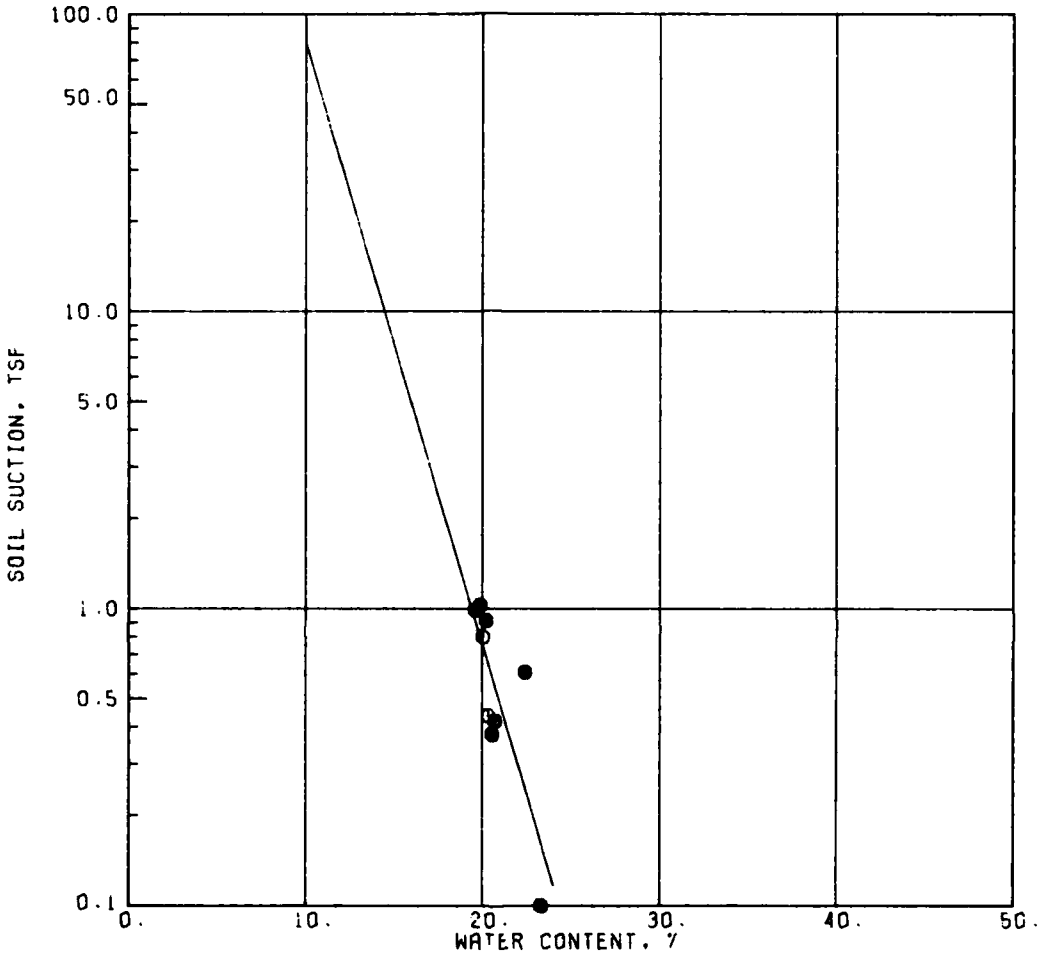
SITE: LAKE CHARLES, LA
BOR: U-2 SAM: 4 DEP: 6.8-



SOIL SUCTION VERSUS WATER CONTENT RELATIONSHIP USING FILTER PAPER & MILLER '78 CALIBRATION CURVE

LOG SOIL SUCTION = 6.7279 -0.3117 * WATER CONTENT

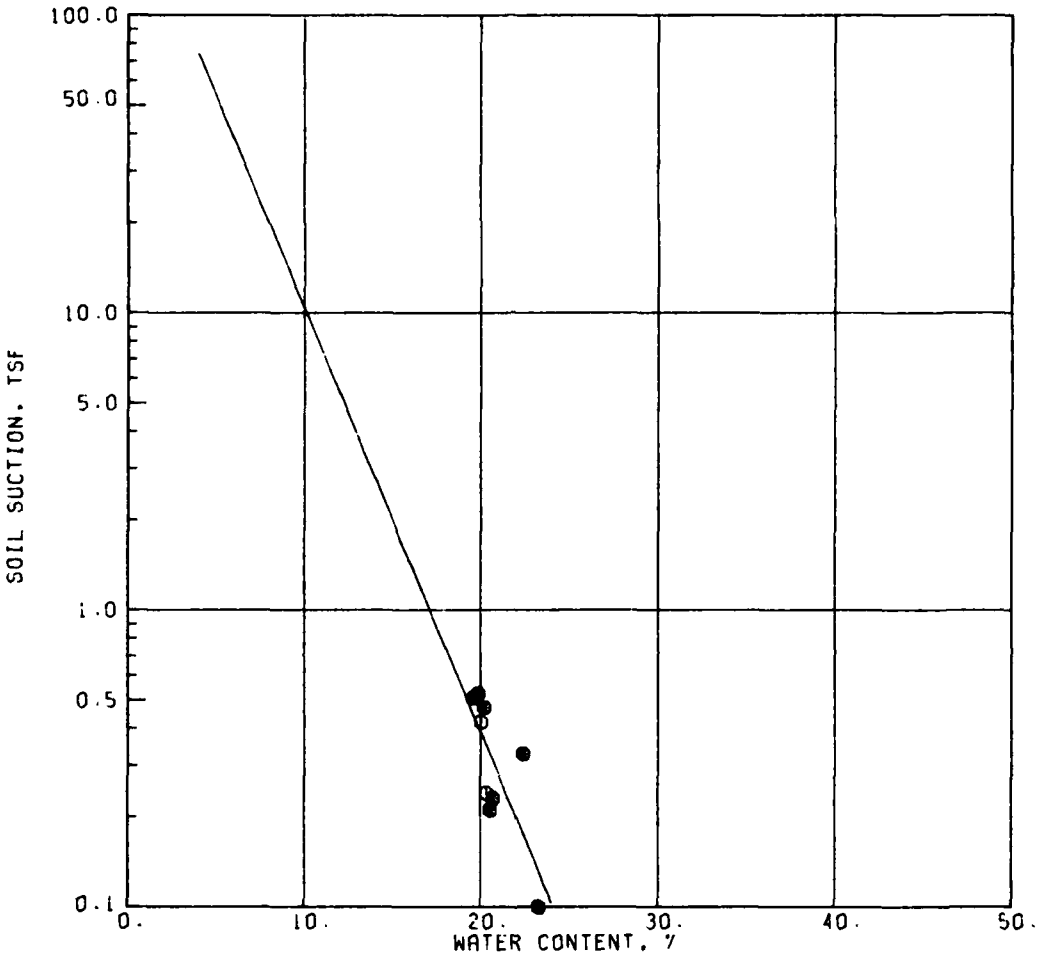
SITE: LAKE CHARLES, LA
BOR: U-2 SAM: 4 DEP: 6.8-



SOIL SUCTION VERSUS WATER CONTENT RELATIONSHIP USING FILTER PAPER & W.E.S.-I '79 CALIBRATION CURVE

LOG SOIL SUCTION = 3.9232 -0.2023 * WATER CONTENT

SITE: LAKE CHARLES, LA
BOR: U-2 SAM: 4 DEP: 6.8-



SOIL SUCTION VERSUS WATER CONTENT RELATIONSHIP USING FILTER PAPER & W.E.S.-II '79 CALIBRATION CURVE

LOG SOIL SUCTION = 2.4449 -0.1428 * WATER CONTENT

SITE: LAKE CHARLES, LA
BOR: U-2 SAM: 4 DEP: 6.8-

- TABLE 1 - SOIL SUCTION AND WATER CONTENT DATA USING THERMOCOUPLE PSYCHROMETER

SITE: SAN ANTONIO, TX
BOR: U-2 SAM: 9 DEP: 10.9-13.1 FT

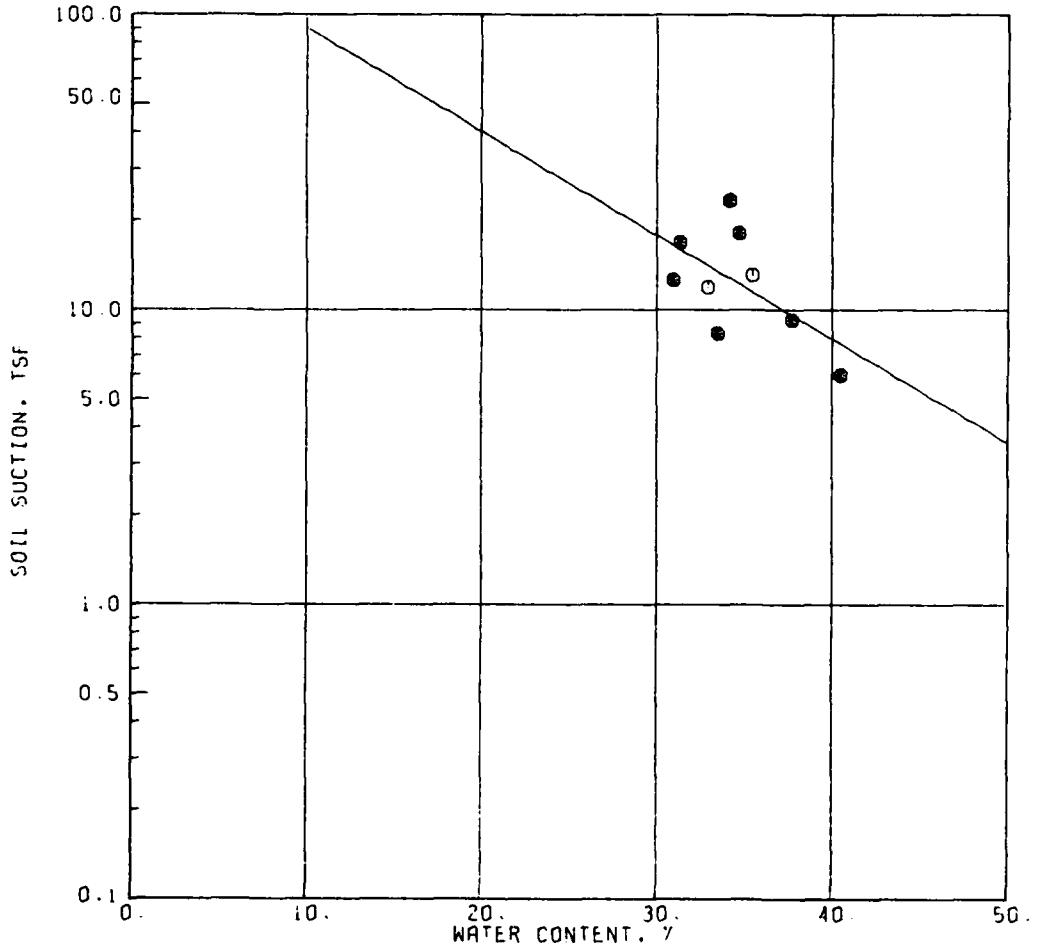
SPECIMEN NUMBER	SOIL SUCTION, TSF	WATER CONTENT %
1	13.1	35.4
2	12.0	32.9
3	12.6	31.0
4	8.3	33.5
5	9.3	37.7
6	6.0	40.5
7	17.0	31.4
8	18.2	34.7
9	23.5	34.2

LOG SOIL SUCTION = 2.3063 -0.0351 * WC

- TABLE 2 - SOIL SUCTION AND WATER CONTENT DATA USING FILTER PAPER AND CALIBRATION CURVES

SITE: SAN ANTONIO, TX
BOR: U-2 SAM: 9 DEP: 10.9-13.1 FT

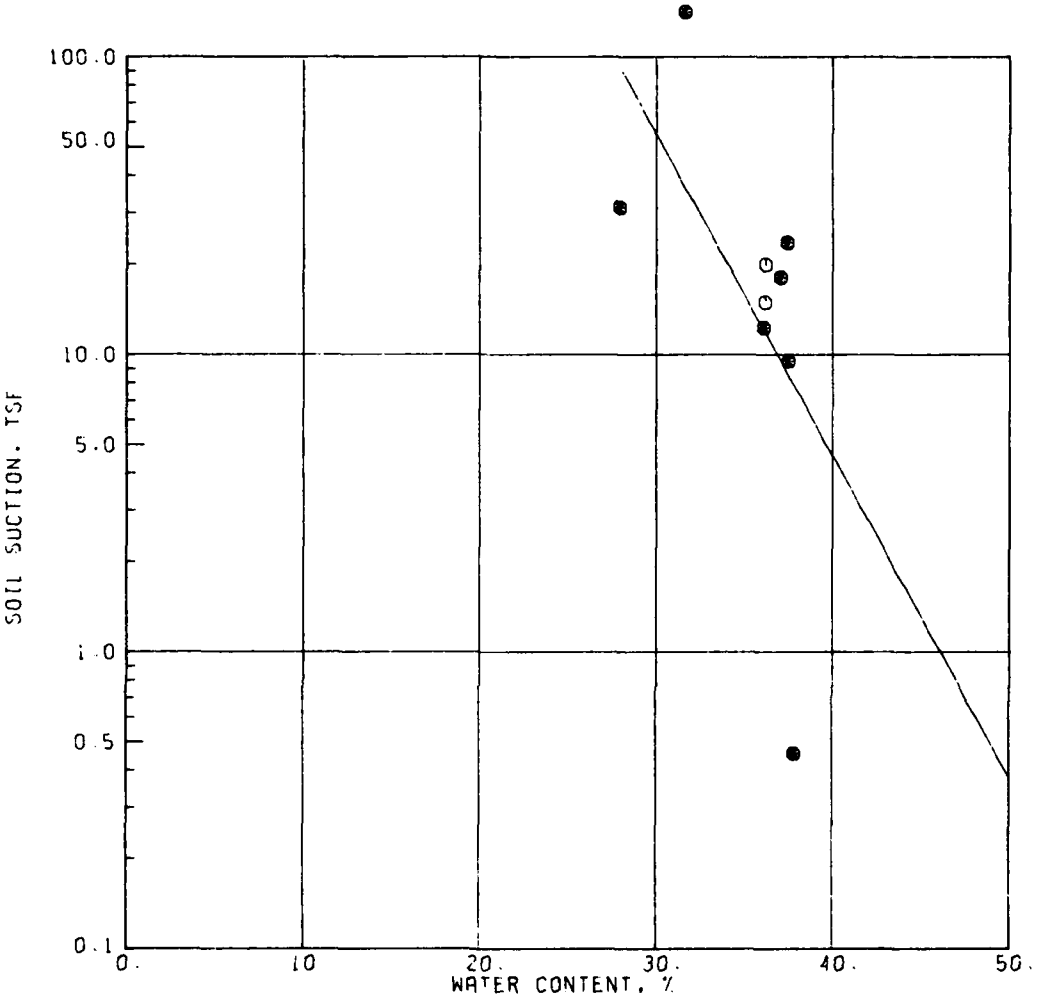
SPECIMEN NUMBER	MOISTURE CONTENT FILTER PAPER %	- - - SOIL SUCTION, TSF - - - McQUEEN/ MILLER 1968	MILLER 1978	W.E.S. I 1979	W.E.S. II 1979	SOIL WATER CONTENT %
1	27.01	20.1	14.7	9.5	3.9	36.19
2	28.77	15.0	11.5	6.6	2.8	36.18
3	29.95	12.3	9.8	5.1	2.2	36.09
4	27.62	18.2	13.5	8.3	3.5	37.00
5	31.50	9.5	8.0	3.7	1.7	37.50
6	49.76	0.5	0.7	0.1	0.1	37.84
7	15.28	141.8	72.2	110.8	35.5	31.67
8	26.00	23.8	16.8	11.7	4.7	37.43
9	24.37	31.2	21.0	16.5	6.4	27.95



SOIL SUCTION VERSUS WATER CONTENT RELATIONSHIP USING THERMOCOUPLE PSYCHROMETERS

LOG SOIL SUCTION = 2.3063 -0.0351 * WATER CONTENT

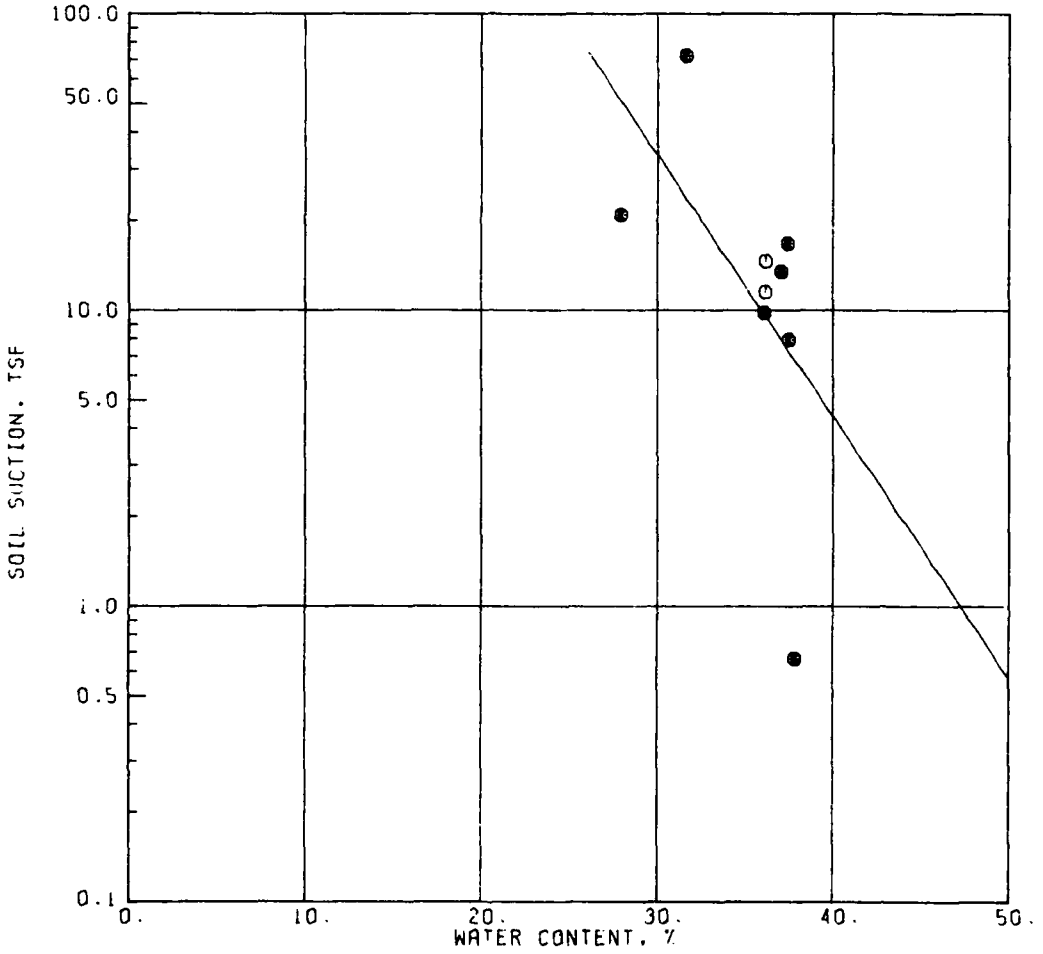
SITE: SAN ANTONIO, TX
BOR: U-2 SAM: 9 DEP: 10.9



SOIL SUCTION VERSUS WATER CONTENT RELATIONSHIP USING FILTER PAPER & MCQUEEN/MILLER '68 CALIBRATION CURVE

LOG SOIL SUCTION = 4.9849 -0.1081 * WATER CONTENT

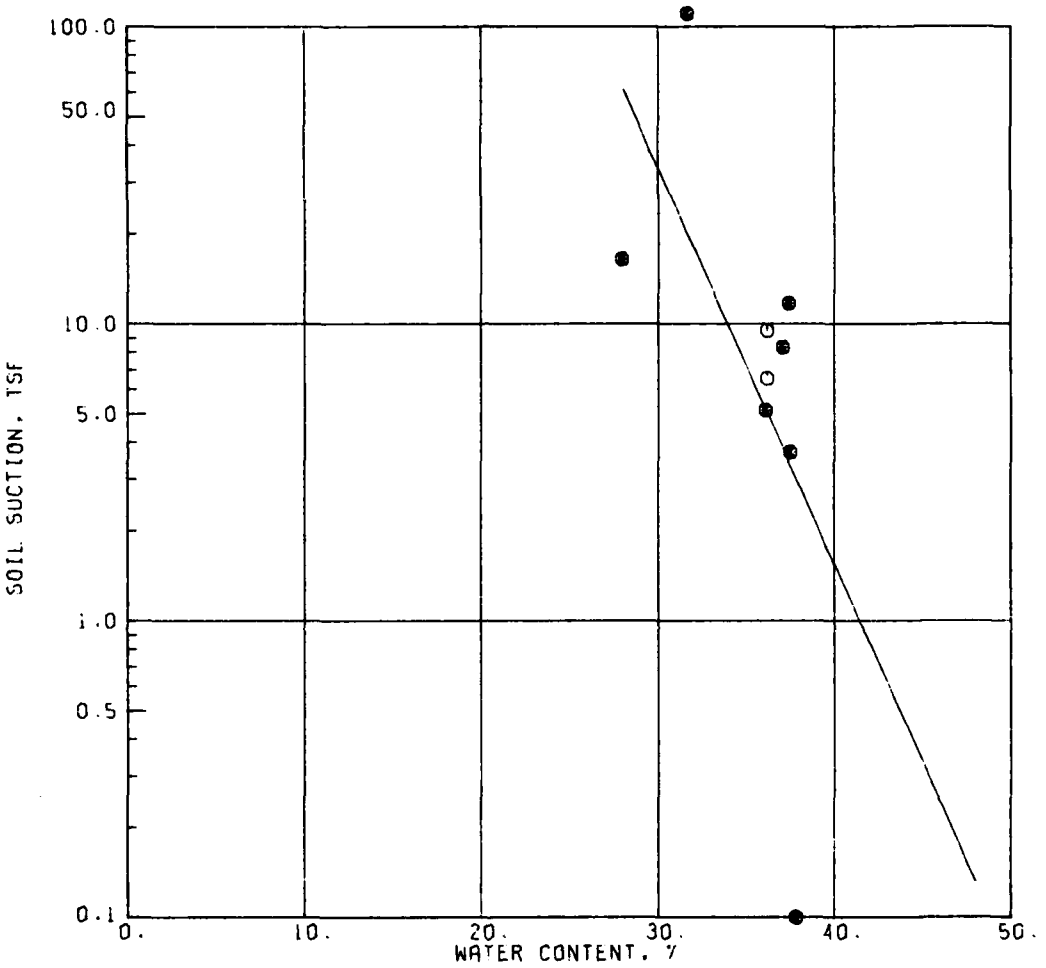
SITE: SAN ANTONIO, TX
BOR: U-2 SAM: 9 DEP: 10.9



SOIL SUCTION VERSUS WATER CONTENT RELATIONSHIP USING FILTER PAPER & MILLER '78 CALIBRATION CURVE

LOG SOIL SUCTION = 4.1707 -0.0882 * WATER CONTENT

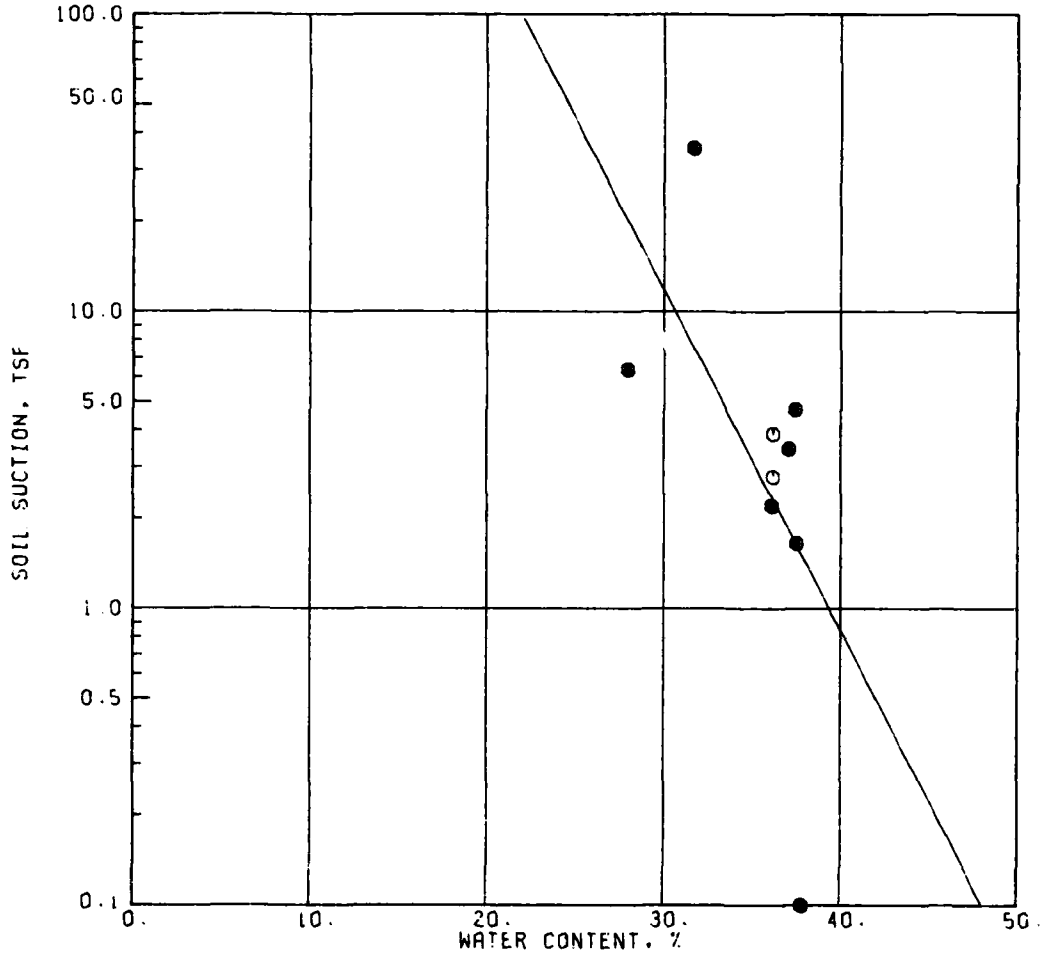
SITE: SAN ANTONIO, TX
BOR: U-2 SAM: 9 DEP: 10.9



SOIL SUCTION VERSUS WATER CONTENT RELATIONSHIP USING FILTER PAPER & W.E.S.-I '79 CALIBRATION CURVE

LOG SOIL SUCTION = 5.5273 -0.1334 * WATER CONTENT

SITE: SAN ANTONIO, TX
BOR: U-2 SAM: 9 DEP: 10.9



SOIL SUCTION VERSUS WATER CONTENT RELATIONSHIP USING FILTER PAPER & W.E.S.-II '79 CALIBRATION CURVE

LOG SOIL SUCTION = 4.5153 -0.1147 * WATER CONTENT

SITE: SAN ANTONIO, TX
BOR: U-2 SAM: 9 DEP: 10.9

- TABLE 1 - SOIL SUCTION AND WATER CONTENT DATA
USING THERMOCOUPLE PSYCHROMETER

SITE: VERNON, TX
BOR: U-1 SAM: 7 DEP: 9.9-11.3 FT

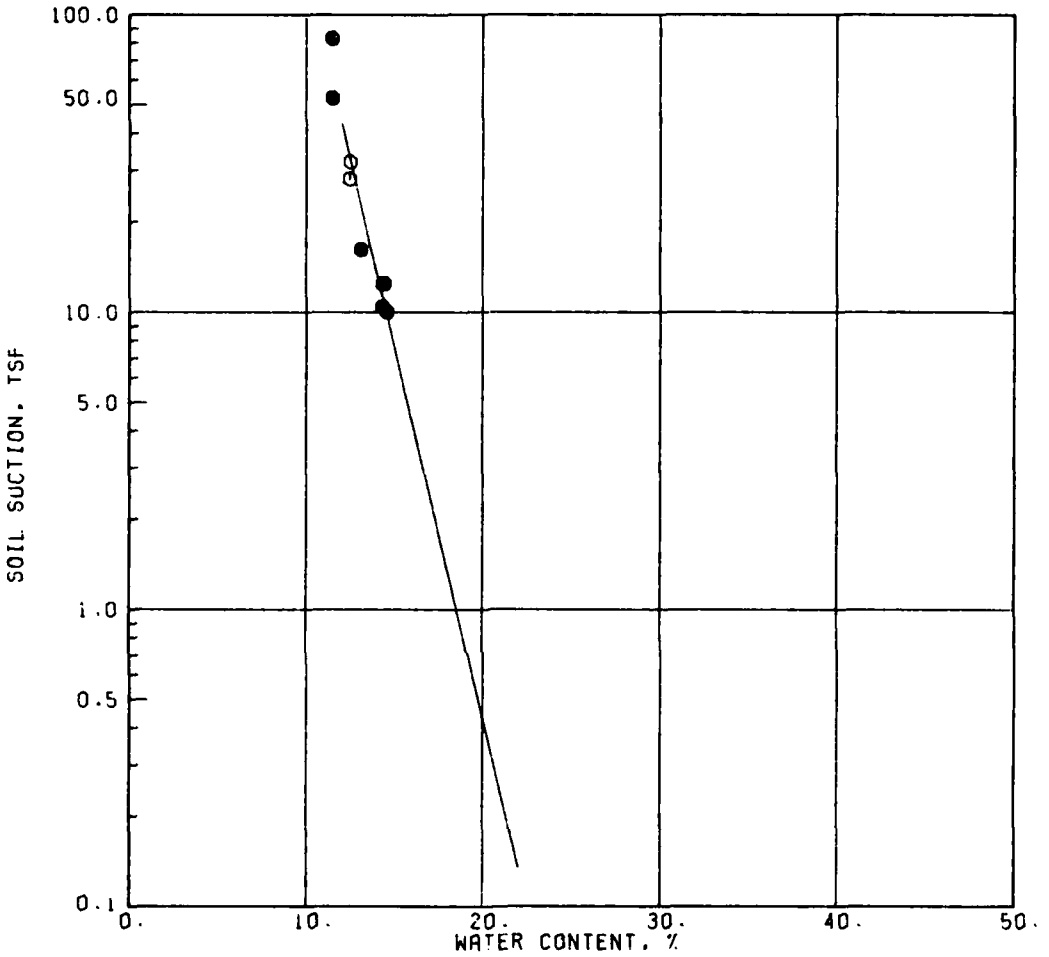
SPECIMEN NUMBER	SOIL SUCTION, TSF	WATER CONTENT %
1	28.0	12.5
2	32.0	12.5
3	16.3	13.1
4	12.5	14.5
5	10.4	14.3
6	10.0	14.6
7	12.4	14.4
8	52.4	11.5
9	83.3	11.5

LOG SOIL SUCTION = 4.6399 -0.2503 * WC

- TABLE 2 - SOIL SUCTION AND WATER CONTENT DATA
USING FILTER PAPER AND CALIBRATION CURVES

SITE: VERNON, TX
BOR: U-1 SAM: 7 DEP: 9.9-11.3 FT

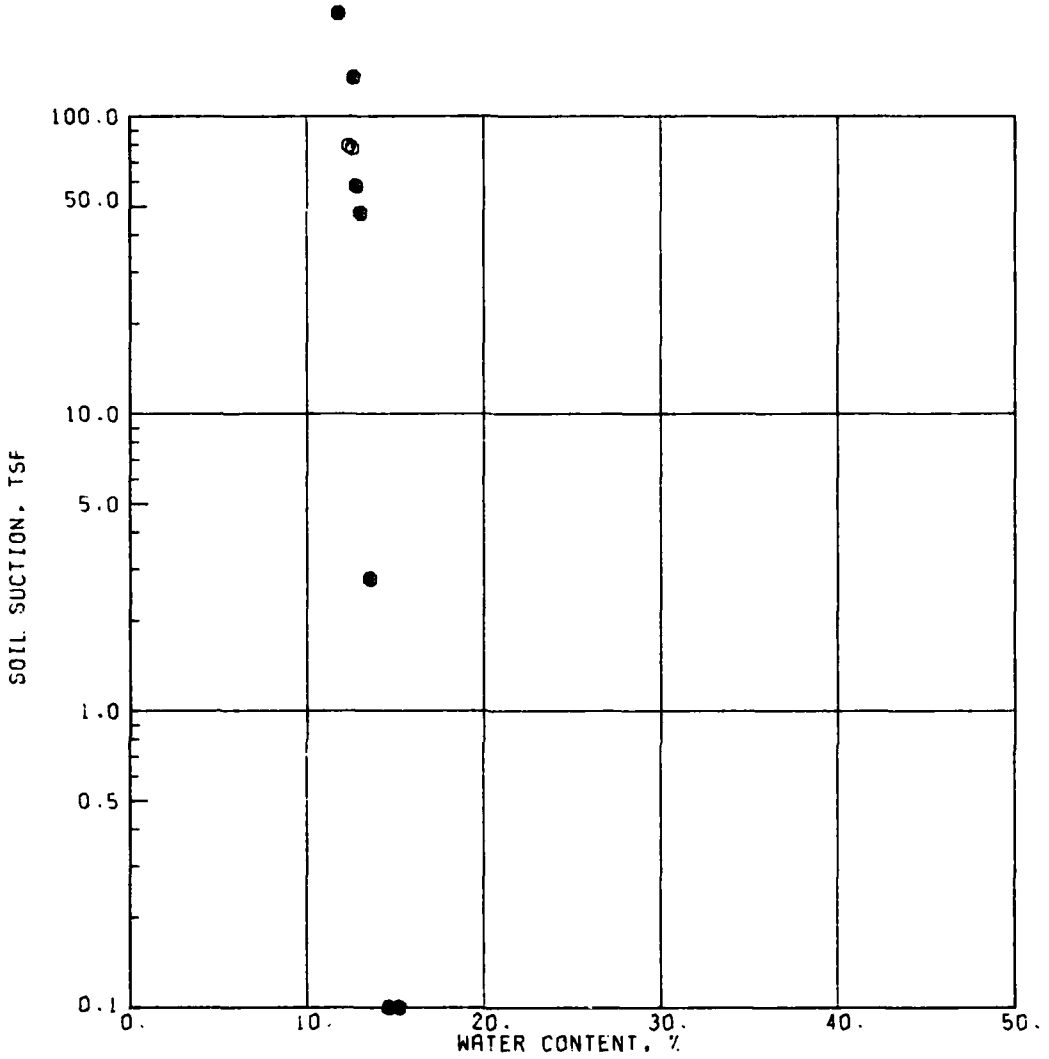
SPECIMEN NUMBER	MOISTURE CONTENT FILTER PAPER %	- - - SOIL SUCTION, TSF - - - McQUEEN/ MILLER 1968	MILLER 1978	W.E.S. I 1979	W.E.S. II 1979	SOIL WATER CONTENT %
1	18.87	78.0	44.4	52.2	18.0	12.58
2	18.75	79.6	45.1	53.5	18.4	12.36
3	20.62	58.3	35.0	36.2	13.0	12.78
4	21.89	47.2	29.4	27.7	10.2	13.04
5	38.91	2.8	2.9	0.8	0.4	13.56
6	218.45	0.1	0.1	0.1	0.1	14.64
7	225.49	0.1	0.1	0.1	0.1	15.22
8	15.56	135.4	69.6	104.6	33.7	12.65
9	12.57	222.8	104.4	195.7	59.2	11.75



SOIL SUCTION VERSUS WATER CONTENT RELATIONSHIP USING THERMOCOUPLE PSYCHROMETERS

LOG SOIL SUCTION = 4.6399 -0.2503 * WATER CONTENT

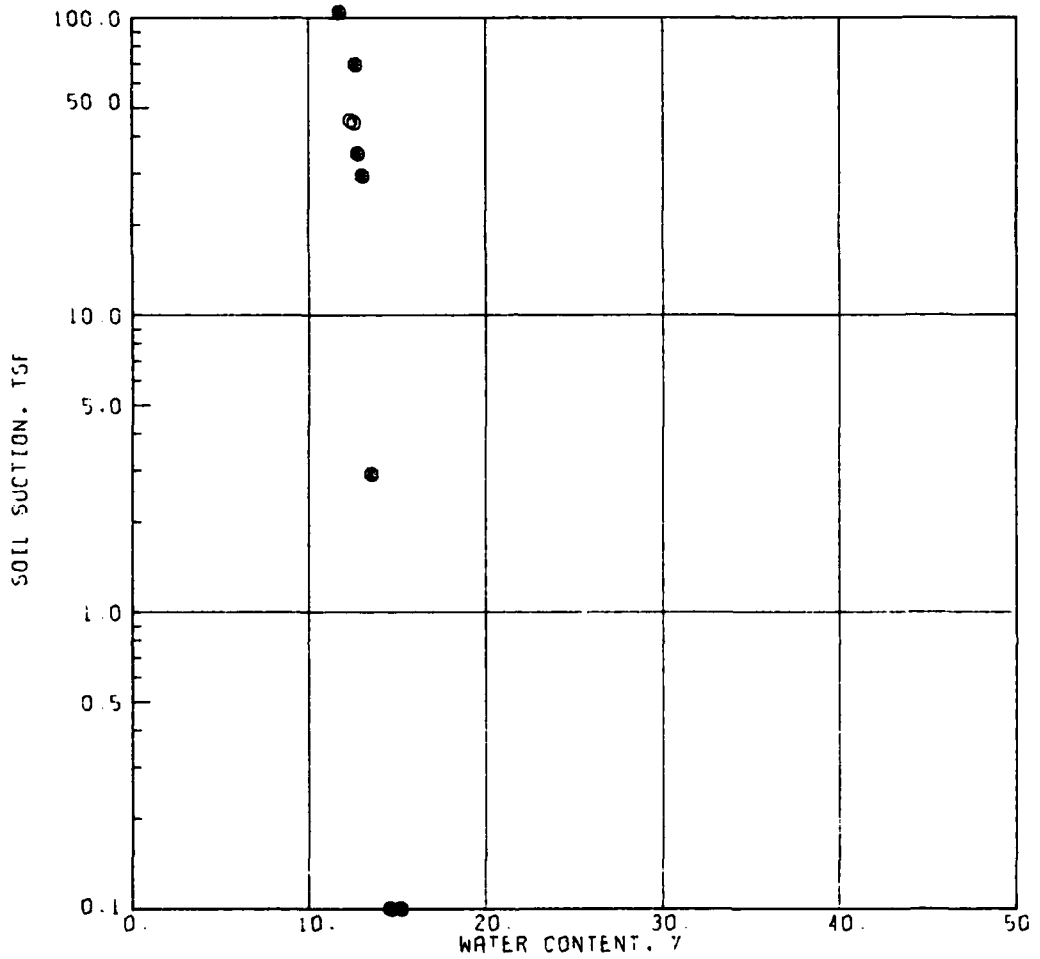
SITE: VERNON, TX
BOR: U-1 SAM: 7 DEP: 9.9-



SOIL SUCTION VERSUS WATER CONTENT RELATIONSHIP USING FILTER PAPER & MCQUEEN/MILLER '68 CALIBRATION CURVE

LOG SOIL SUCTION = 16.2038 -1.1443 * WATER CONTENT

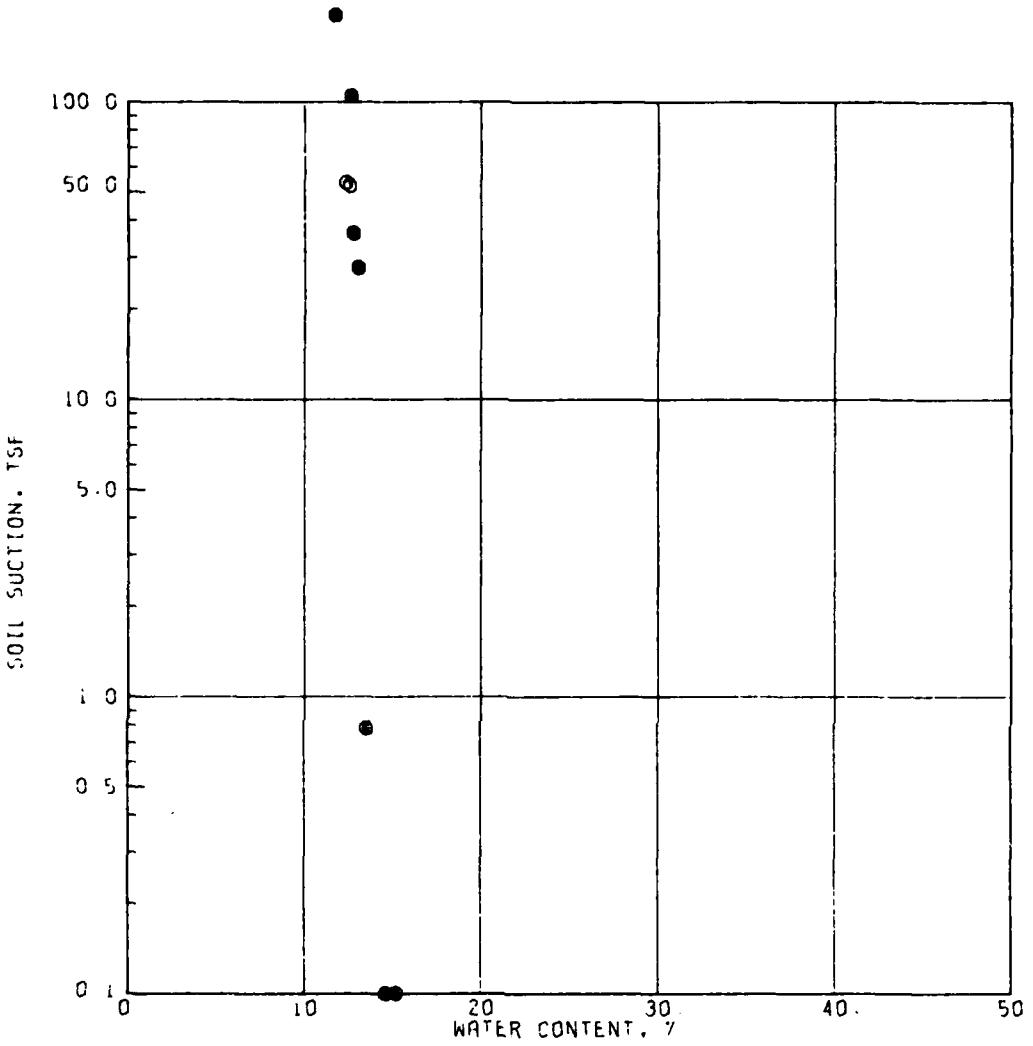
SITE: VERNON, TX
BOR: U-1 SAM: 7 DEP: 9.9-



SOIL SUCTION VERSUS WATER CONTENT RELATIONSHIP USING FILTER PAPER & MILLER '78 CALIBRATION CURVE

LOG SOIL SUCTION = 14.5919 -1.0348 * WATER CONTENT

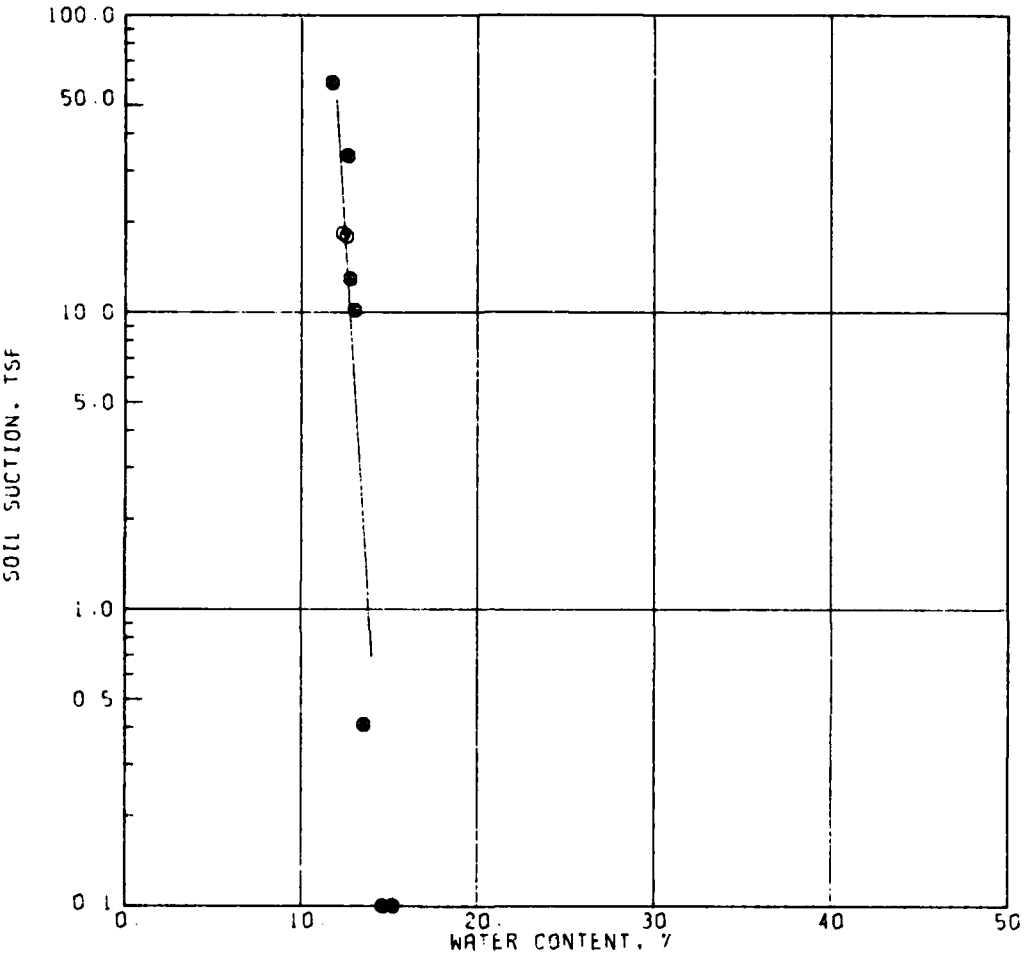
SITE: VERNON, TX
BOR: U-1 SAM: 7 DEP: 9.9-



SOIL SUCTION VERSUS WATER CONTENT RELATIONSHIP USING FILTER PAPER & W.E.S.-I '79 CALIBRATION CURVE

LOG SOIL SUCTION = 15.6595 -1.1157 * WATER CONTENT

SITE: VERNON, TX
BOR: U-1 SAM: 7 DEP: 9.9-



SOIL SUCTION VERSUS WATER CONTENT RELATIONSHIP USING FILTER PAPER & W.E.S.-II '79 CALIBRATION CURVE

LOG SOIL SUCTION = 12.9648 -0.9373 * WATER CONTENT

SITE: VERNON, TX
SOR: U-1 SAM: 7 DEP: 9.9-

- TABLE 1 - SOIL SUCTION AND WATER CONTENT DATA
USING THERMOCOUPLE PSYCHROMETER

SITE: DURANT, OK
BOR: U-2 SAM: 4 DEP: 6.6-9.2 FT

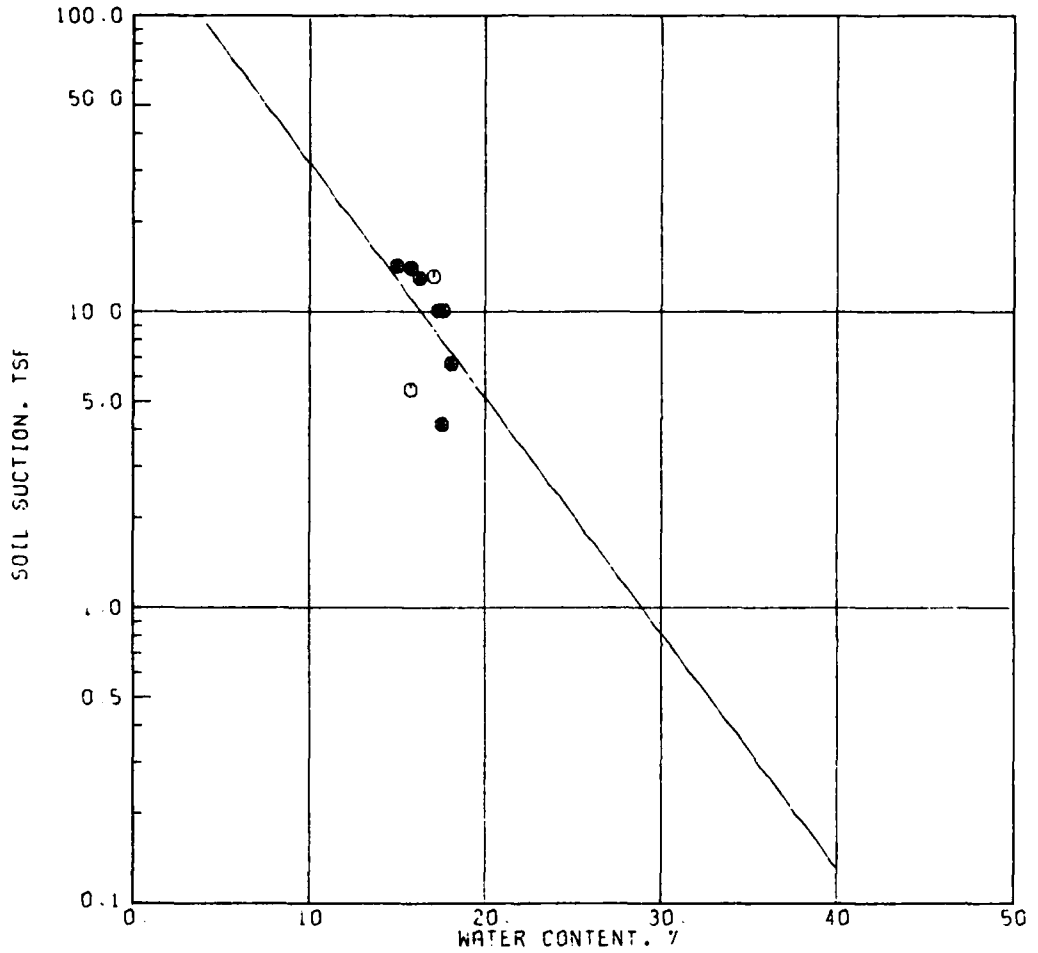
SPECIMEN NUMBER	SOIL SUCTION, TSF	WATER CONTENT %
1	13.1	17.0
2	5.5	15.7
3	10.1	17.3
4	6.7	18.1
5	10.1	17.6
6	4.2	17.5
7	13.0	16.2
8	14.0	15.8
9	14.2	15.0

LOG SOIL SUCTION = 2.2964 -0.0795 * WC

- TABLE 2 - SOIL SUCTION AND WATER CONTENT DATA
USING FILTER PAPER AND CALIBRATION CURVES

SITE: DURANT, OK
BOR: U-2 SAM: 4 DEP: 6.6-9.2 FT

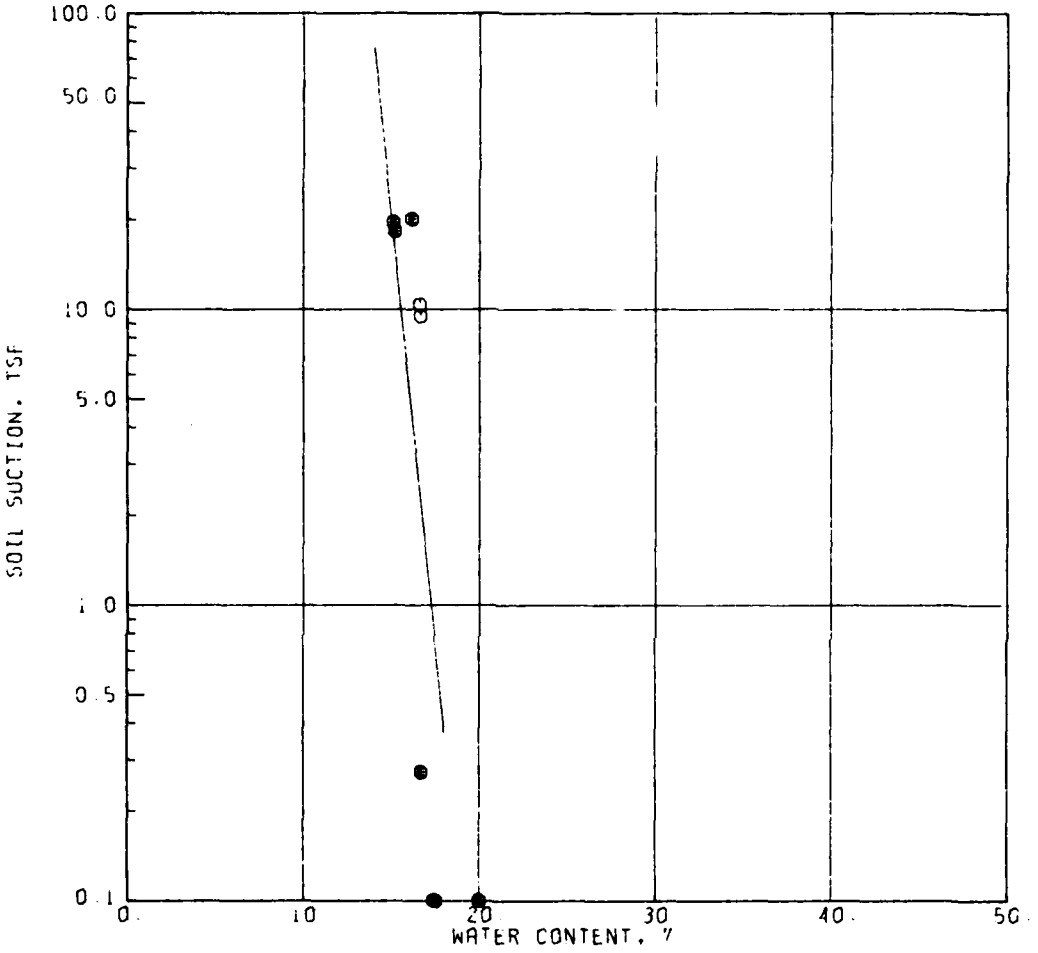
SPECIMEN NUMBER	MOISTURE CONTENT FILTER PAPER %	- - - SOIL SUCTION, TSF - - - McQUEEN/ MILLER 1968	MILLER 1978	W.E.S. I 1979	W.E.S. II 1979	Soil Water Content %
1	31.53	9.5	7.9	3.7	1.6	16.05
2	31.00	10.4	8.5	4.1	1.8	16.07
3	52.86	0.3	0.4	0.1	0.1	18.70
4	81.86	0.1	0.1	0.1	0.1	17.51
5	139.06	0.1	0.1	0.1	0.1	20.00
6	212.63	0.1	0.1	0.1	0.1	17.30
7	27.00	20.2	14.7	9.5	3.9	16.16
8	27.15	19.7	14.4	9.2	3.8	15.12
9	27.55	18.4	13.6	8.5	3.5	15.19



SOIL SUCTION VERSUS WATER CONTENT RELATIONSHIP USING THERMOCOUPLE PSYCHROMETERS

LOG SOIL SUCTION = 2.2964 -0.0795 * WATER CONTENT

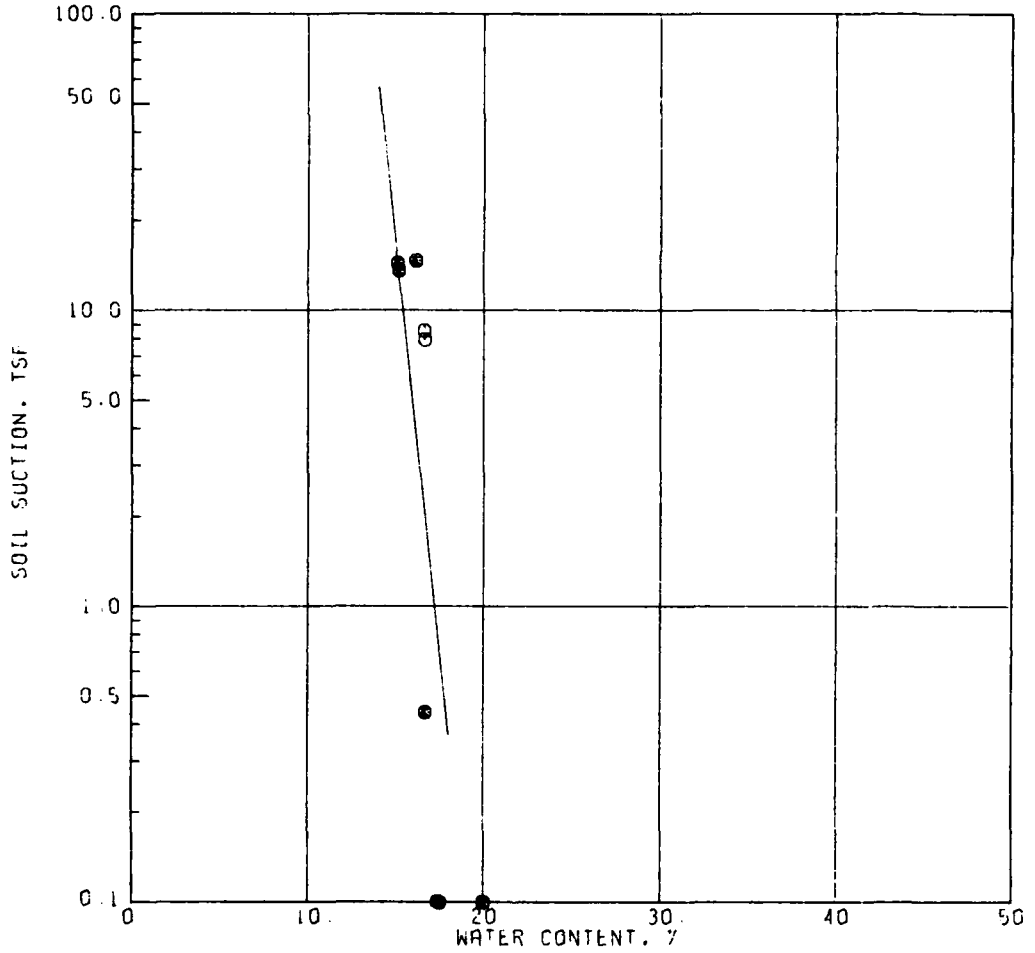
SITE: DURANT, OK
BOR: U-2 SAM: 4 DEP: 6.6-



SOIL SUCTION VERSUS WATER CONTENT RELATIONSHIP USING FILTER PAPER & MCQUEEN/MILLER '68 CALIBRATION CURVE

LOG SOIL SUCTION = 9.9979 -0.5794 * WATER CONTENT

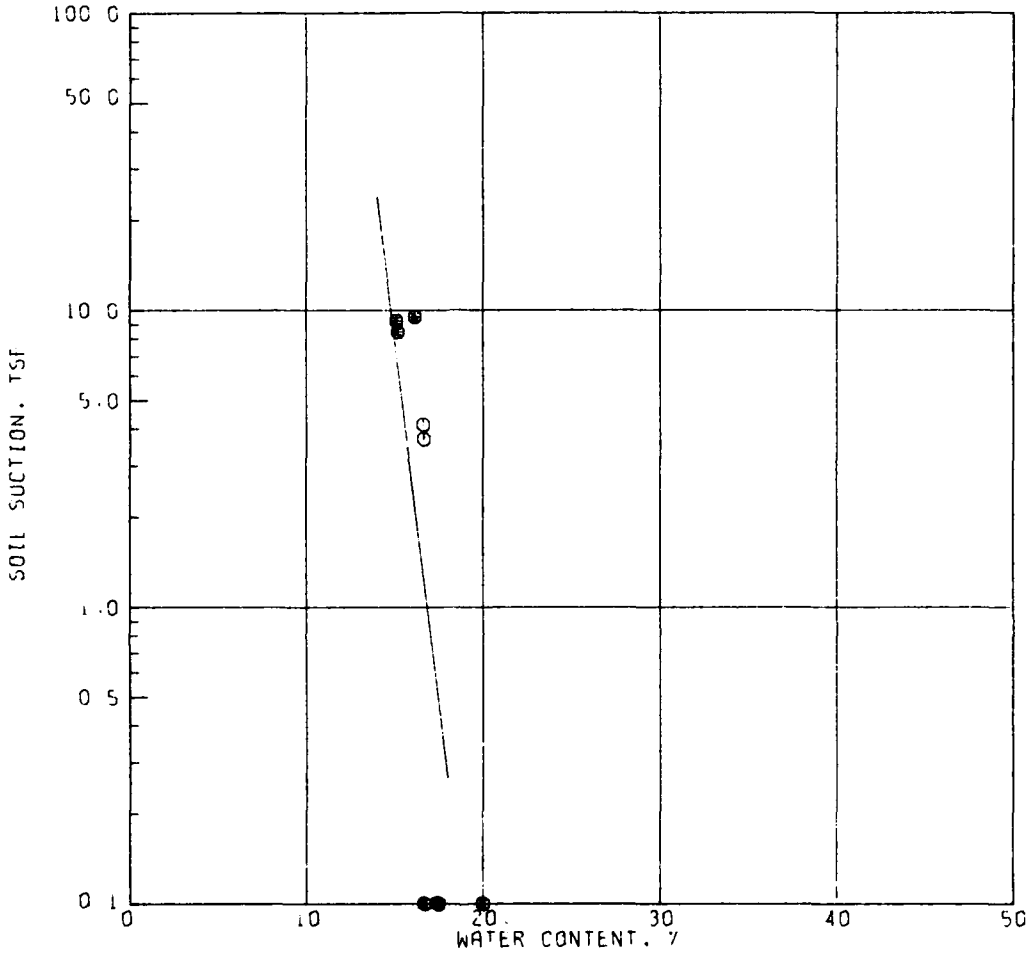
SITE: DURANT, OK
BOR: U-2 SAM: 4 DEP: 6.6-



SOIL SUCTION VERSUS WATER CONTENT RELATIONSHIP USING FILTER PAPER & MILLER '78 CALIBRATION CURVE

LOG SOIL SUCTION = 9.4298 -0.5480 * WATER CONTENT

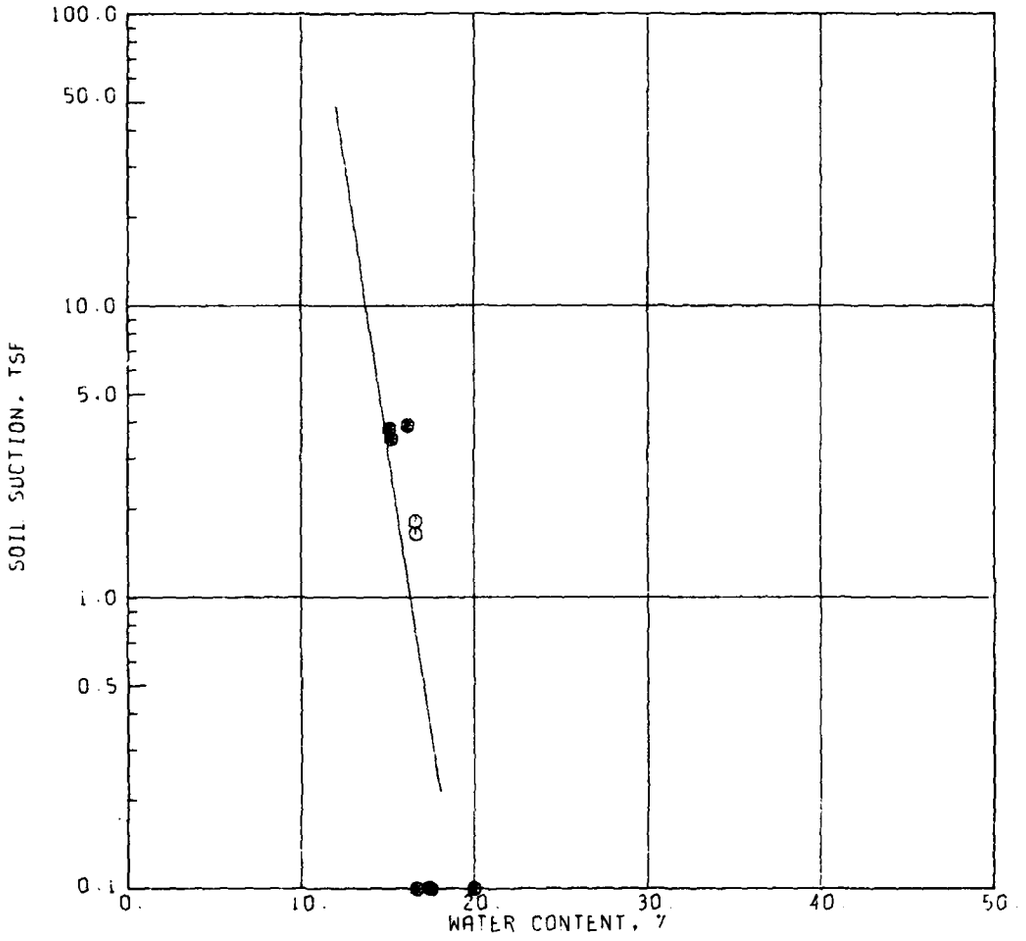
SITE: DURANT, OK
BOR: U-2 SAM: 4 DEP: 6.6-



SOIL SUCTION VERSUS WATER CONTENT RELATIONSHIP USING FILTER PAPER & W.E.S.-I '79 CALIBRATION CURVE

LOG SOIL SUCTION = 8.2492 -0.4902 * WATER CONTENT

SITE: DURANT, OK
BOR: U-2 SAM: 4 DEP: 6.6-



SOIL SUCTION VERSUS WATER CONTENT RELATIONSHIP USING FILTER PAPER & W.E.S.-I '79 CALIBRATION CURVE

LOG SOIL SUCTION = 6.3976 -0.3924 * WATER CONTENT

SITE: DURANT, OK
BOR: U-2 SAM: 4 DEP: 6.6-

- TABLE 1 - SOIL SUCTION AND WATER CONTENT DATA USING THERMOCOUPLE PSYCHROMETER

SITE: HENNESSEY, OK
BOR: U-1 SAM: 4 DEP: 6.8-8.8 FT

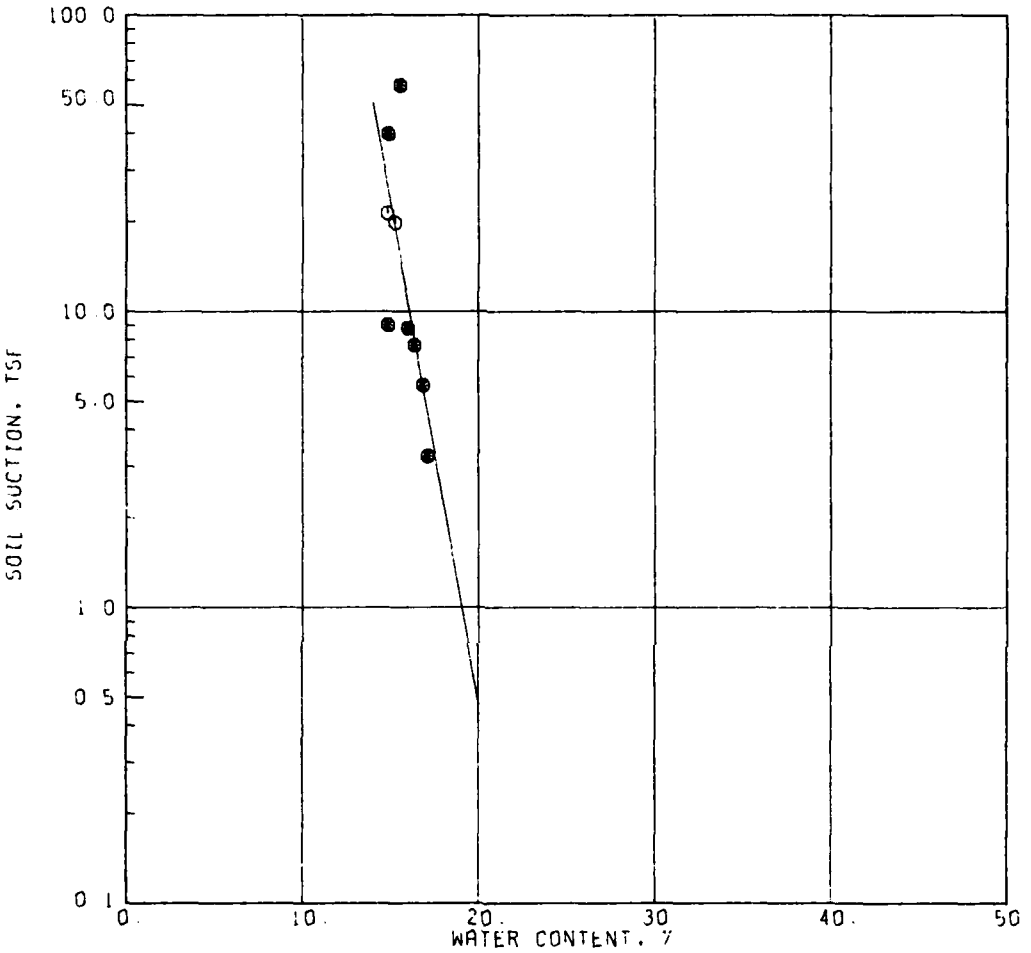
SPECIMEN NUMBER	SOIL SUCTION, TSF	WATER CONTENT %
1	21.5	14.8
2	19.9	15.2
3	9.0	14.9
4	8.8	16.0
5	7.7	16.3
6	3.2	17.1
7	5.6	16.9
8	39.7	14.9
9	58.0	15.6

LOG SOIL SUCTION = 6.4425 -0.3384 * WC

- TABLE 2 - SOIL SUCTION AND WATER CONTENT DATA USING FILTER PAPER AND CALIBRATION CURVES

SITE: HENNESSEY, OK
BOR: U-1 SAM: 4 DEP: 6.8-8.8 FT

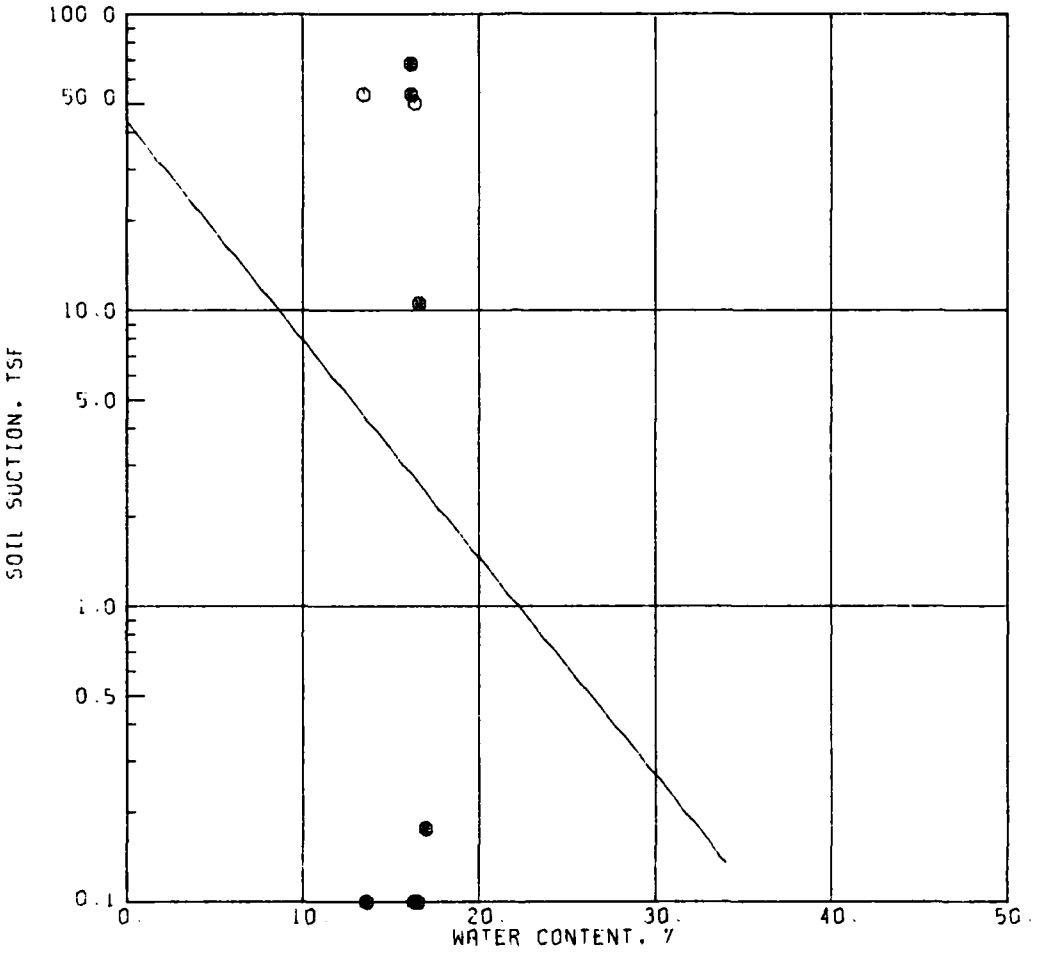
SPECIMEN NUMBER	MOISTURE CONTENT FILTER PAPER %	- - - SOIL SUCTION, TSF - - - McQUEEN/ MILLER 1968	MILLER 1978	W.E.S. I 1979	W.E.S. II 1979	Soil Water Content %
1	21.54	50.0	30.9	29.9	10.9	16.3
2	21.13	53.5	32.6	32.5	11.7	15.86
3	30.88	10.6	8.7	4.2	1.9	16.61
4	55.44	0.2	0.3	0.1	0.1	16.97
5	136.84	0.1	0.1	0.1	0.1	16.5
6	181.77	0.1	0.1	0.1	0.1	16.31
7	185.20	0.1	0.1	0.1	0.1	15.93
8	19.70	68.0	39.6	43.9	15.4	16.14
9	21.13	53.5	32.6	32.5	11.7	16.16



SOIL SUCTION VERSUS WATER CONTENT RELATIONSHIP USING THERMOCOUPLE PSYCHROMETERS

LOG SOIL SUCTION = 6.4425 -0.3384 * WATER CONTENT

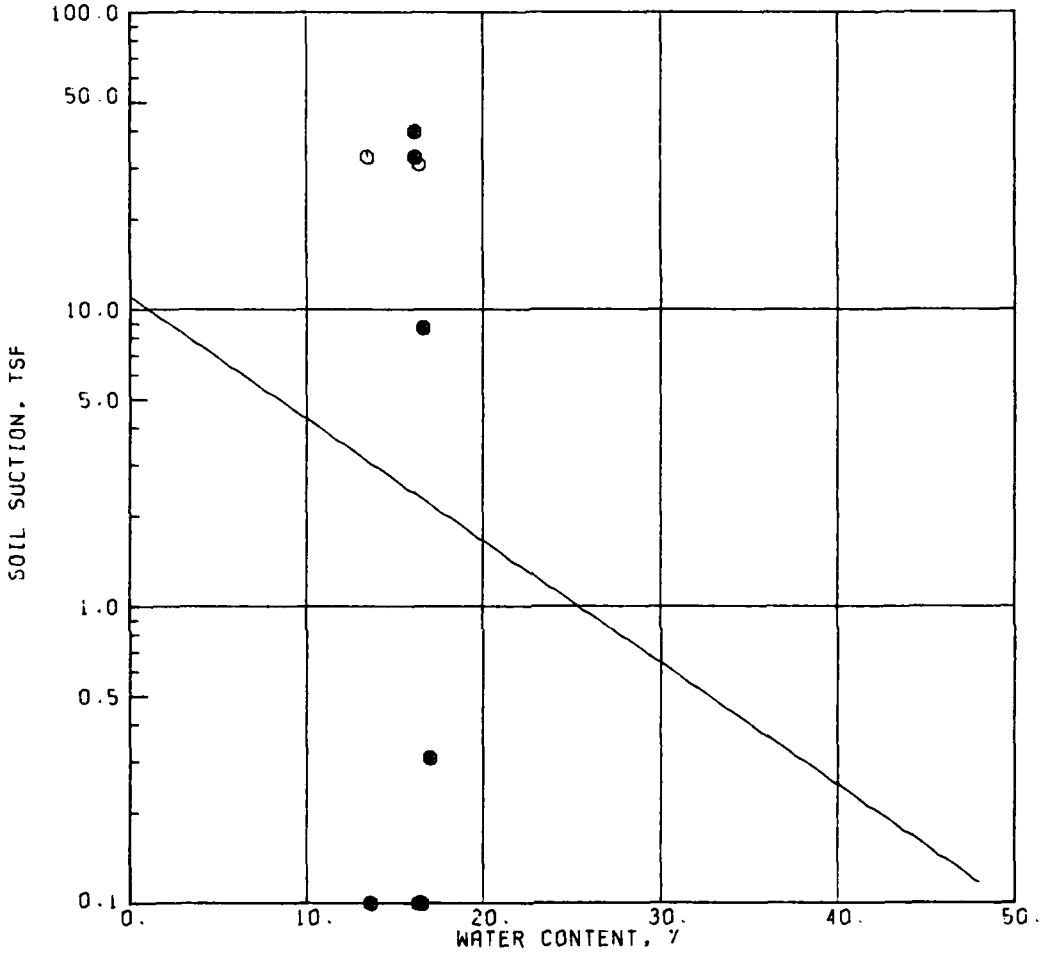
SITE: HENNESSEY, OK
BOR: U-1 SAM: 4 DEP: 6.8-



SOIL SUCTION VERSUS WATER CONTENT RELATIONSHIP USING FILTER PAPER & MCQUEEN/MILLER '68 CALIBRATION CURVE

LOG SOIL SUCTION = 1.6362 -0.0736 * WATER CONTENT

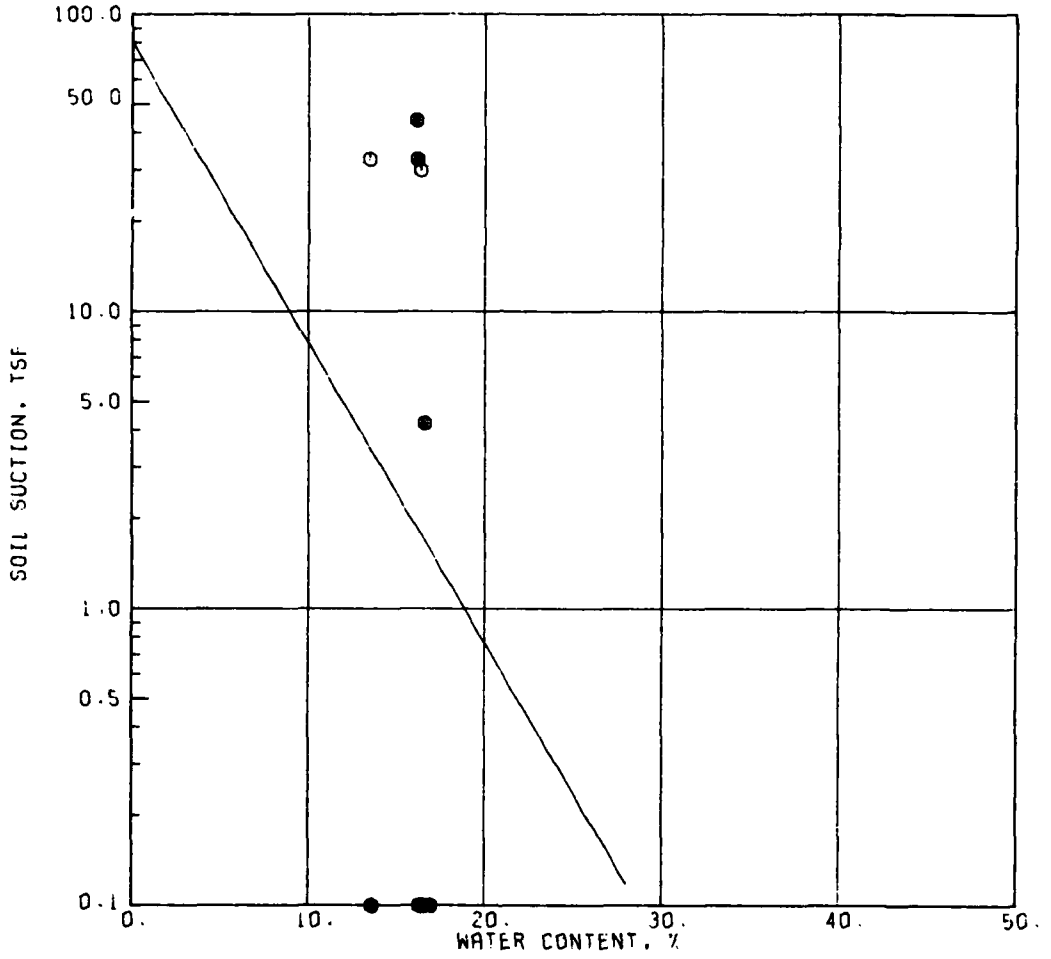
SITE: HENNESSEY, OK
BOR: U-1 SAM: 4 DEP: 6.8-



SOIL SUCTION VERSUS WATER CONTENT RELATIONSHIP USING FILTER PAPER & MILLER '78 CALIBRATION CURVE

LOG SOIL SUCTION = 1.0431 -0.0411 * WATER CONTENT

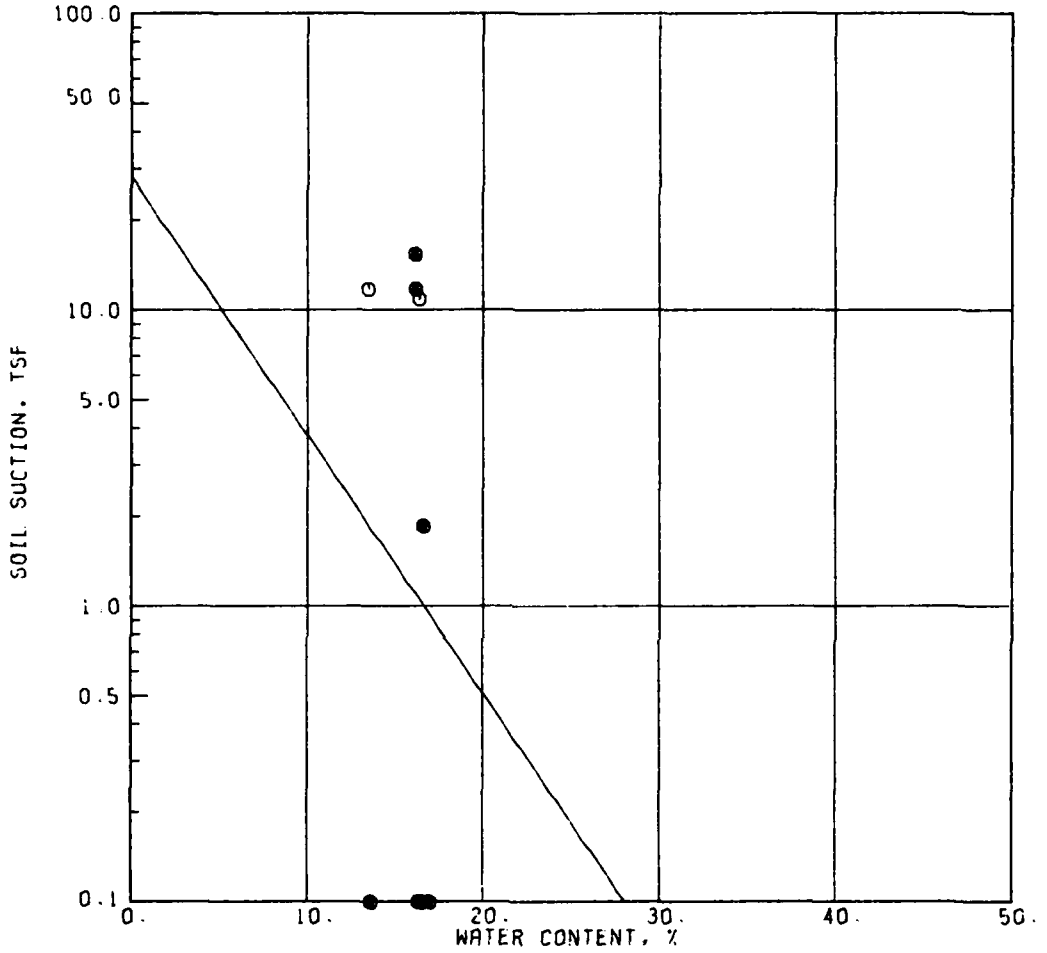
SITE: HENNESSEY, OK
BOR: U-1 SAM: 4 DEP: 6.8-



SOIL SUCTION VERSUS WATER CONTENT RELATIONSHIP USING FILTER PAPER & W.E.S.-I '79 CALIBRATION CURVE

LOG SOIL SUCTION = 1.9041 -0.1010 * WATER CONTENT

SITE: HENNESSEY, OK
BOR: U-1 SAM: 4 DEP: 6.8-



SOIL SUCTION VERSUS WATER CONTENT RELATIONSHIP USING FILTER PAPER & W.E.S.-II '79 CALIBRATION CURVE

LOG SOIL SUCTION = 1.4483 -0.0872 * WATER CONTENT

SITE: HENNESSEY, OK
BOR: U-1 SAM: 4 DEP: 6.8-

- TABLE 1 - SOIL SUCTION AND WATER CONTENT DATA USING THERMOCOUPLE PSYCHROMETER

SITE: HOLBROOK, AZ #1
BOR: U-2 SAM: 4 DEP: 6.7-8.5 FT

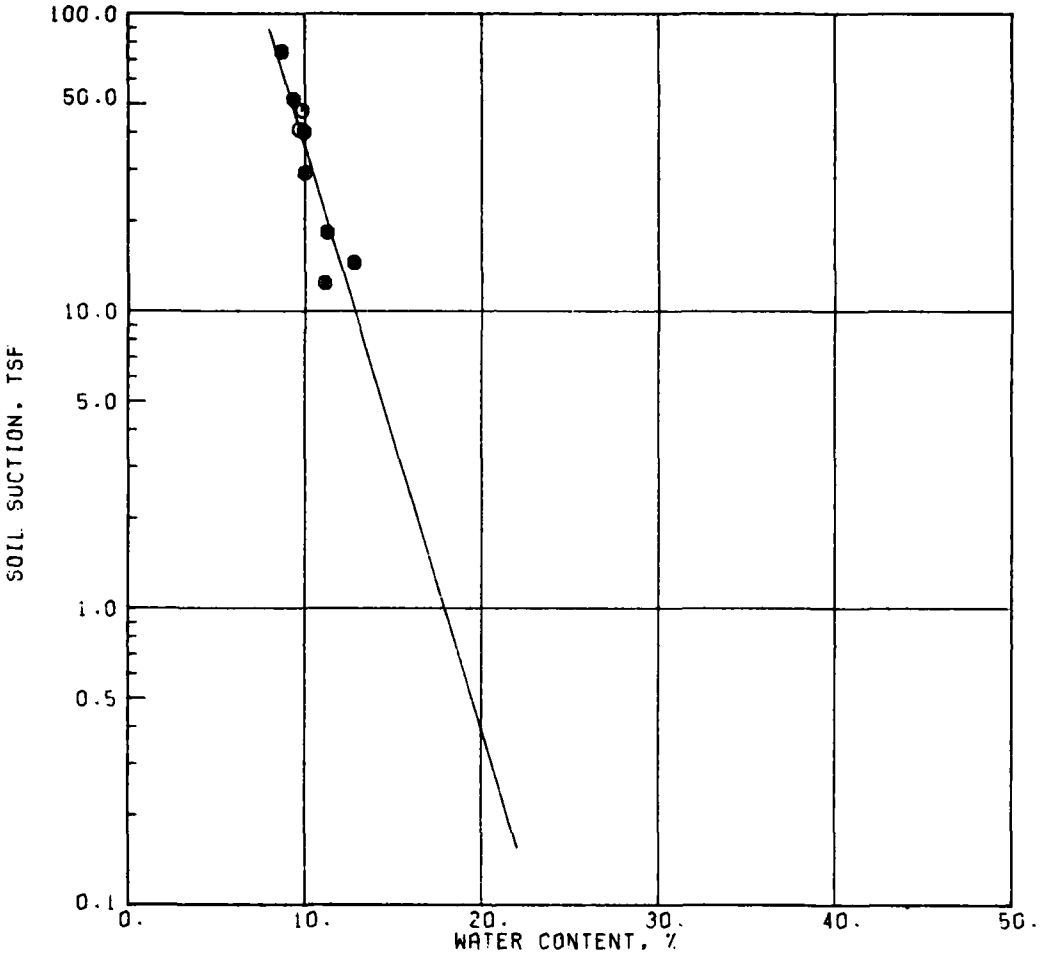
SPECIMEN NUMBER	SOIL SUCTION, TSF	WATER CONTENT %
1	47.3	9.8
2	40.9	9.7
3	40.2	9.9
4	29.3	10.0
5	18.5	11.3
6	12.5	11.1
7	14.6	12.8
8	51.6	9.3
9	74.7	8.7

LOG SOIL SUCTION = 3.5207 -0.1966 * WC

- TABLE 2 - SOIL SUCTION AND WATER CONTENT DATA USING FILTER PAPER AND CALIBRATION CURVES

SITE: HOLBROOK, AZ #1
BOR: U-2 SAM: 4 DEP: 6.7-8.5 FT

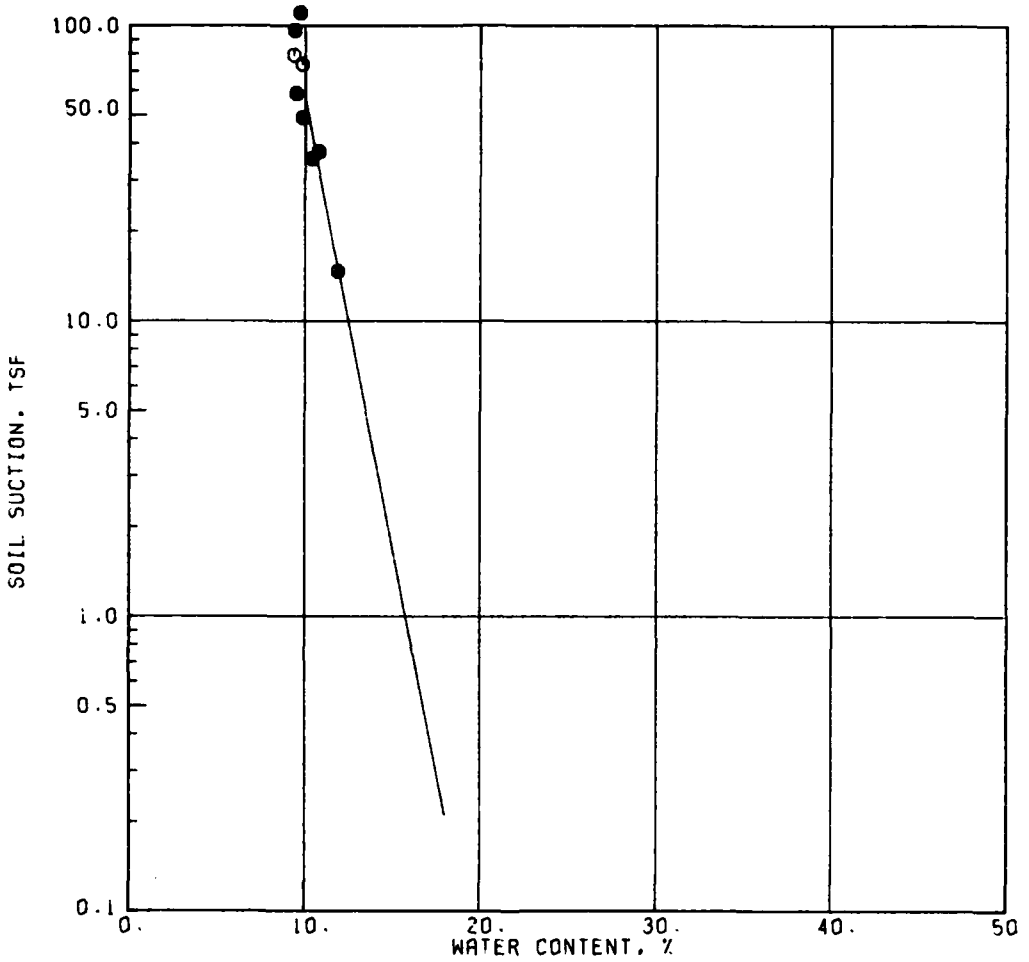
SPECIMEN NUMBER	MOISTURE CONTENT FILTER PAPER %	- - - SOIL SUCTION, TSF - - - McQUEEN/ MILLER 1968	MILLER 1978	W.E.S. I 1979	W.E.S. II 1979	SOIL WATER CONTENT %
1	19.17	74.2	42.6	49.0	17.0	9.84
2	18.75	79.6	45.1	53.5	18.4	9.37
3	20.54	59.1	35.4	36.8	13.2	9.50
4	21.67	48.9	30.3	29.0	10.6	9.87
5	23.59	35.6	23.4	19.4	7.4	10.39
6	23.27	37.5	24.4	20.8	7.9	10.78
7	28.87	14.8	11.4	6.4	2.7	11.89
8	17.59	96.6	52.8	68.3	23.0	9.41
9	16.75	111.0	59.1	81.4	26.9	9.73



SOIL SUCTION VERSUS WATER CONTENT RELATIONSHIP USING THERMOCOUPLE PSYCHROMETERS

LOG SOIL SUCTION = 3.5207 -0.1966 * WATER CONTENT

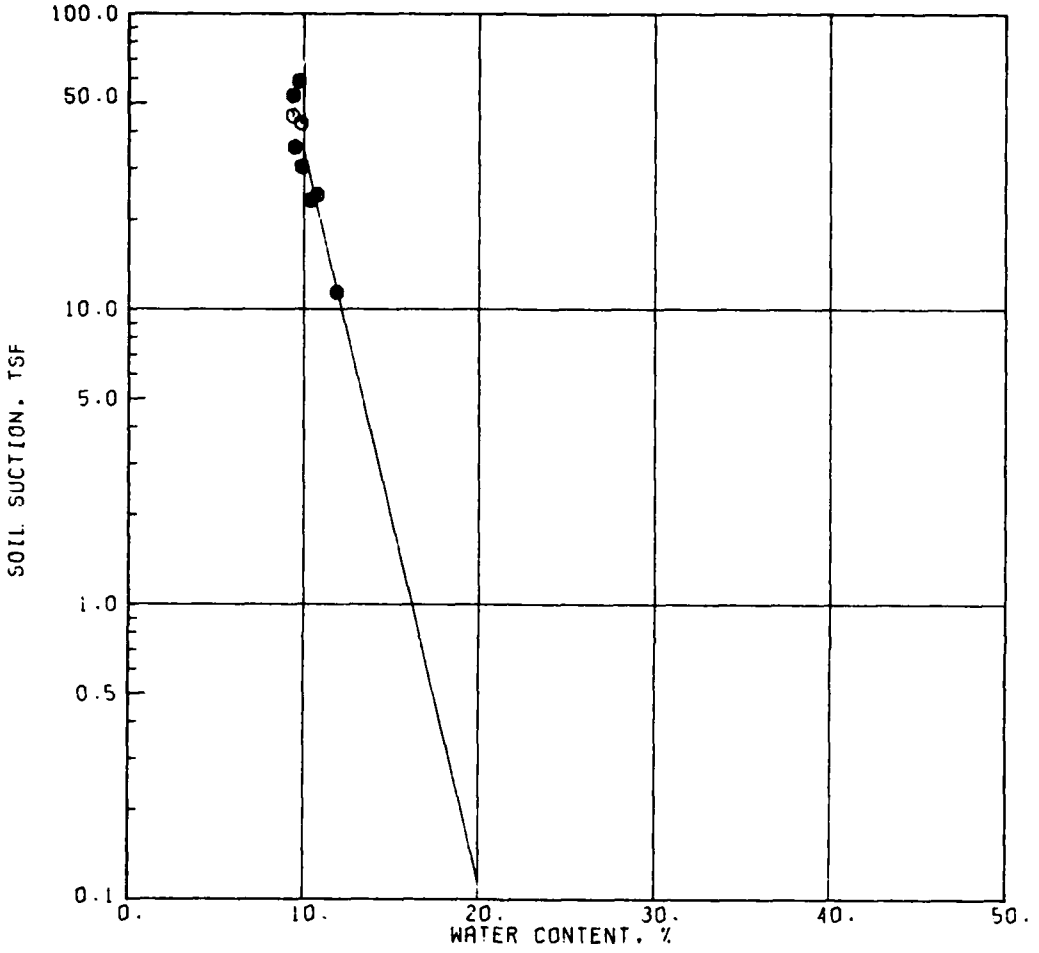
SITE: HOLBROOK, AZ #1
BOR: U-2 SAM: 4 DEP: 6.7-



SOIL SUCTION VERSUS WATER CONTENT RELATIONSHIP USING FILTER PAPER & MCQUEEN/MILLER '68 CALIBRATION CURVE

LOG SOIL SUCTION = 4.7863 -0.3032 * WATER CONTENT

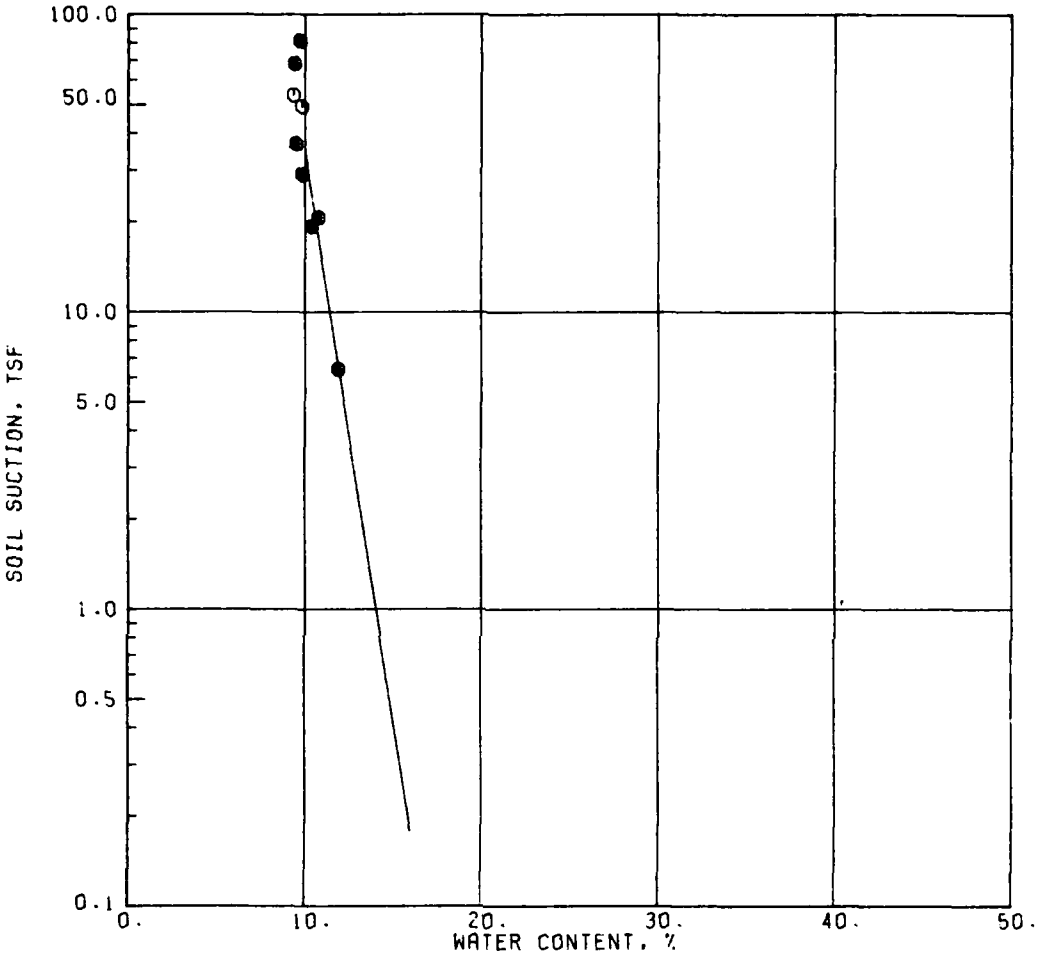
SITE: HOLBROOK, AZ #1
BOR: U-2 SAM: 4 DEP: 6.7-



SOIL SUCTION VERSUS WATER CONTENT RELATIONSHIP USING FILTER PAPER & MILLER '78 CALIBRATION CURVE

LOG SOIL SUCTION = 4.0086 -0.2474 * WATER CONTENT

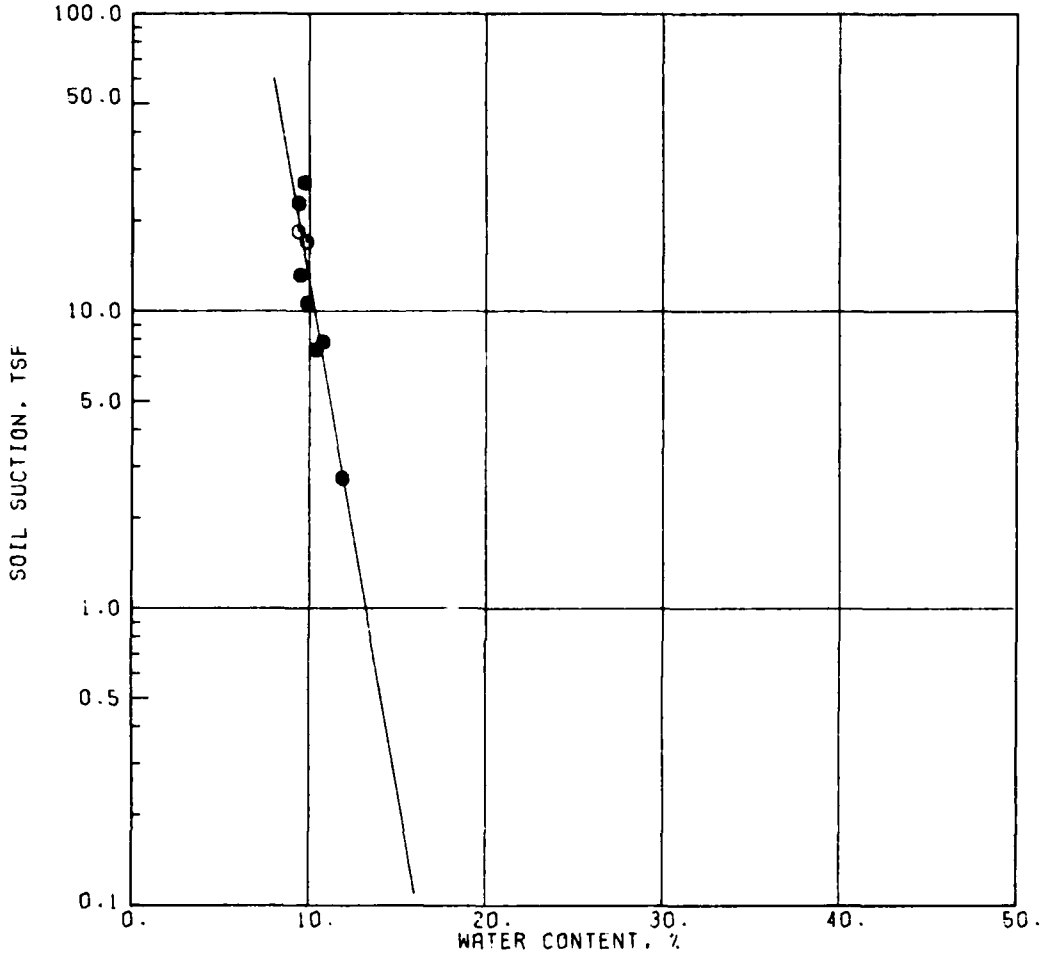
SITE: HOLBROOK, AZ #1
BOR: U-2 SAM: 4 DEP: 6.7-



SOIL SUCTION VERSUS WATER CONTENT RELATIONSHIP USING FILTER PAPER & W.E.S.-I '79 CALIBRATION CURVE

LOG SOIL SUCTION = 5.3605 -0.3816 * WATER CONTENT

SITE: HOLBROOK, AZ #1
BOR: U-2 SAM: 4 DEP: 6.7-



SOIL SUCTION VERSUS WATER CONTENT RELATIONSHIP USING FILTER PAPER & W.E.S.-II '79 CALIBRATION CURVE

LOG SOIL SUCTION = 4.5381 -0.3439 * WATER CONTENT

SITE: HOLBROOK, AZ #1
BOR: U-2 SAM: 4 DEP: 6.7-

- TABLE 1 - SOIL SUCTION AND WATER CONTENT DATA
USING THERMOCOUPLE PSYCHROMETER

SITE: HOLBROOK, AZ #2
BOR: U-2 SAM: 4 DEP: 6.8-9.0 FT

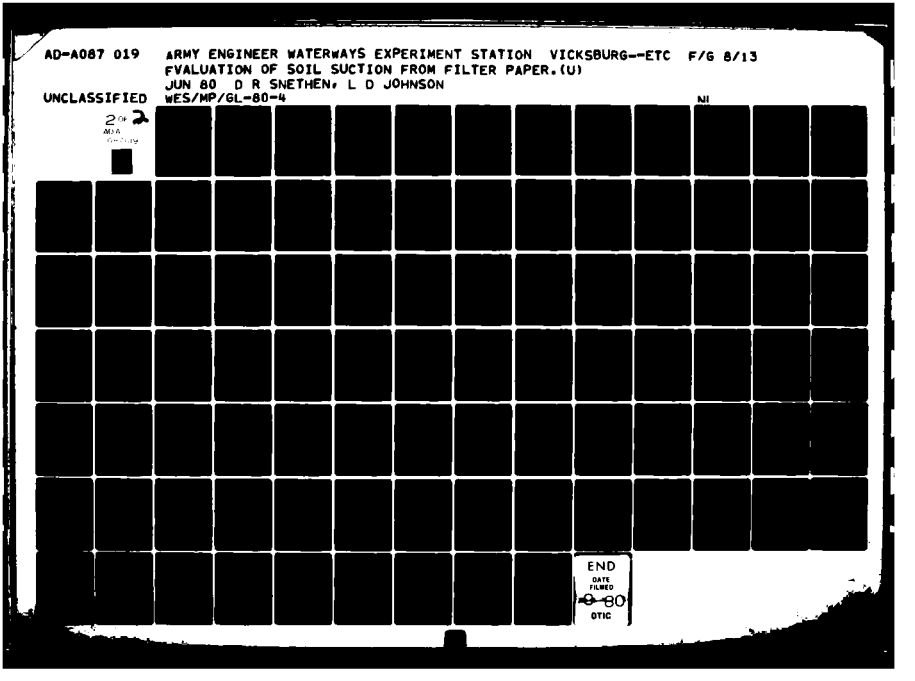
SPECIMEN NUMBER	SOIL SUCTION, TSF	WATER CONTENT %
1	88.2	15.7
2	88.6	15.2
3	58.2	17.2
4	45.3	17.5
5	18.0	20.4
6	23.7	19.1
7	17.2	20.5
8	126.5	15.4
9	133.3	14.9

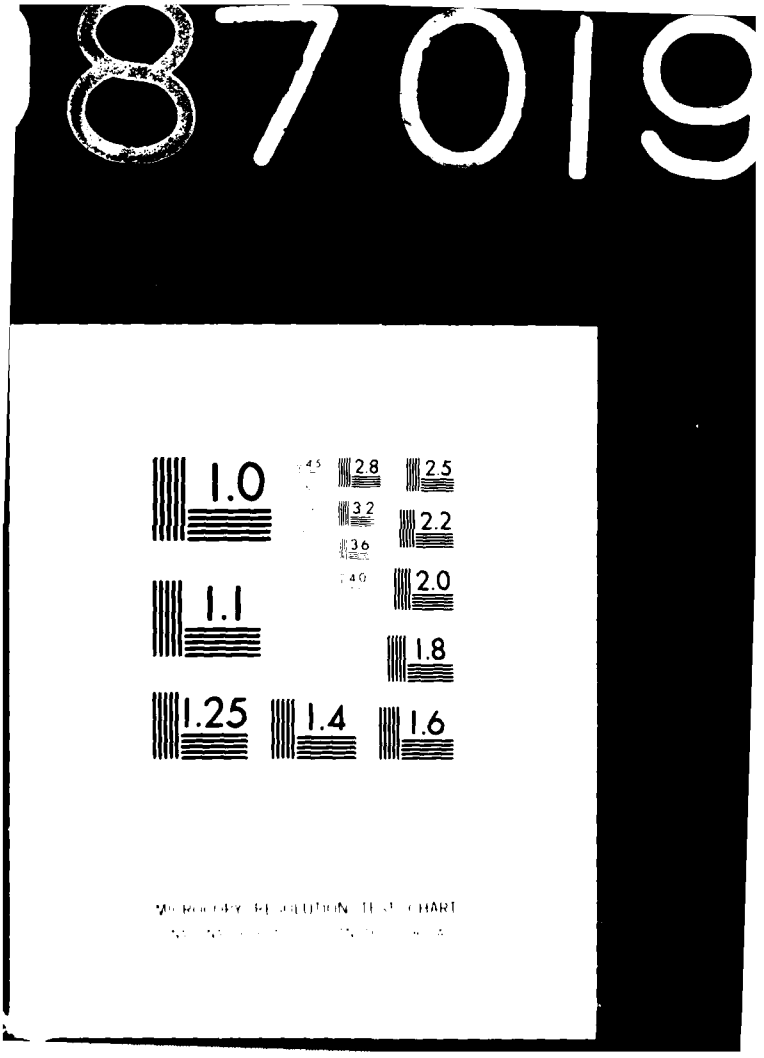
LOG SOIL SUCTION = 4.4100 -0.1558 * WC

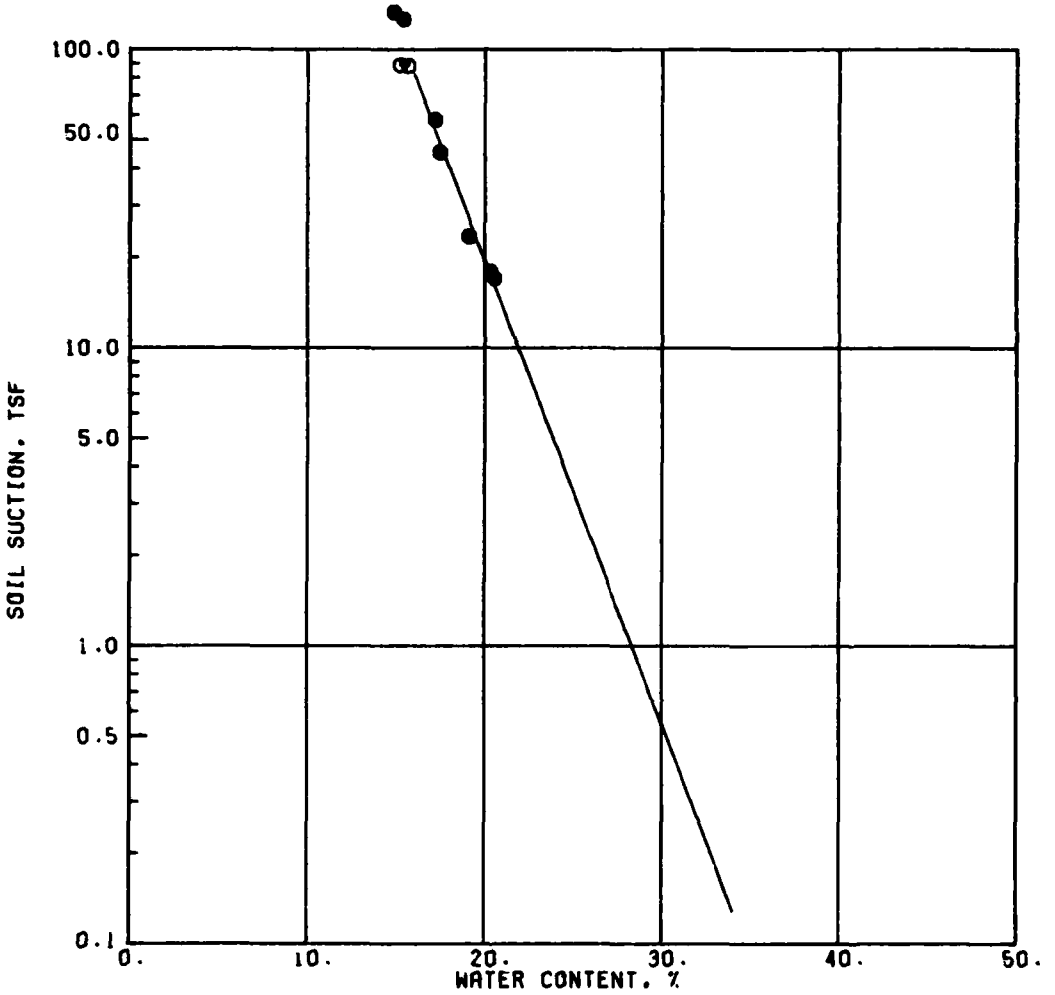
- TABLE 2 - SOIL SUCTION AND WATER CONTENT DATA
USING FILTER PAPER AND CALIBRATION CURVES

SITE: HOLBROOK, AZ #2
BOR: U-2 SAM: 4 DEP: 6.8-9.0 FT

SPECIMEN NUMBER	MOISTURE CONTENT FILTER PAPER %	- - - SOIL SUCTION, TSF - - - McQUEEN/ MILLER 1968	MILLER 1978	W.E.S. I 1979	W.E.S. II 1979	Soil Water Content %
1	14.51	161.2	80.2	130.3	41.1	15.23
2	13.16	201.9	96.4	172.8	53.0	15.52
3	15.89	128.1	66.5	97.5	31.6	16.23
4	19.39	71.6	41.3	46.9	16.3	16.07
5	19.79	66.9	39.1	43.0	15.1	17.18
6	13.02	206.5	98.1	177.8	54.3	17.14
7	41.92	1.7	1.9	0.4	0.2	19.04
8	8.99	403.7	169.6	413.5	116.3	15.03
9	8.21	460.4	188.8	487.9	135.0	14.34


AD-A087 019
ARMY ENGINEER WATERWAYS EXPERIMENT STATION VICKSBURG--ETC F/G 8/13
EVALUATION OF SOIL SUCTION FROM FILTER PAPER.(U)
JUN 80 D R SNETHEN, L D JOHNSON
UNCLASSIFIED
WES/MP/GL-80-4
NL
2 OF 2
END
DATE FILMED
9-80
DTIC

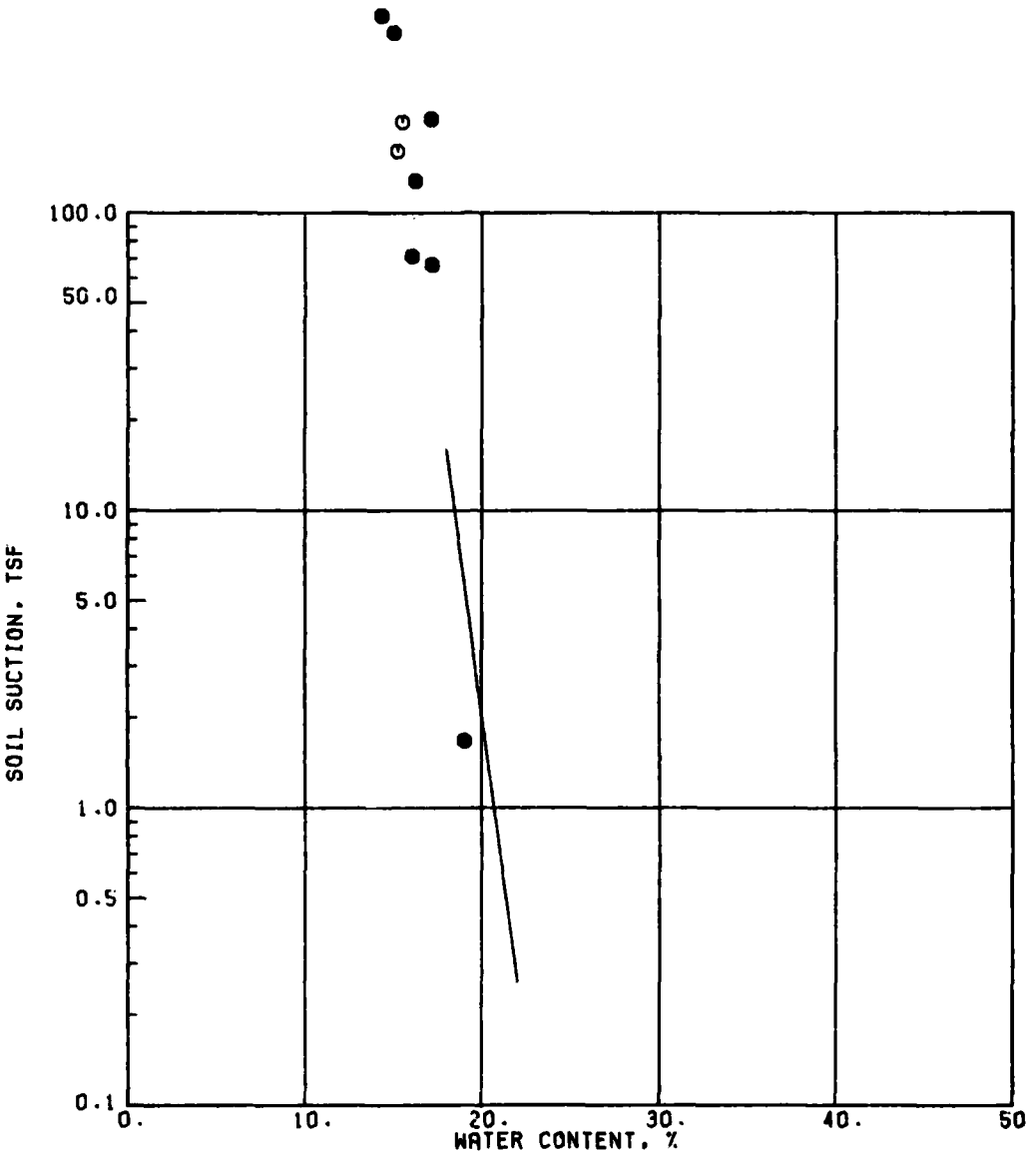

87019
1.0
1.1
1.25
1.4
1.6
2.0
2.2
2.5
2.8
3.2
3.6
4.0
1.8



SOIL SUCTION VERSUS WATER CONTENT RELATIONSHIP USING THERMOCOUPLE PSYCHROMETERS

LOG SOIL SUCTION = 4.4100 -0.1558 * WATER CONTENT

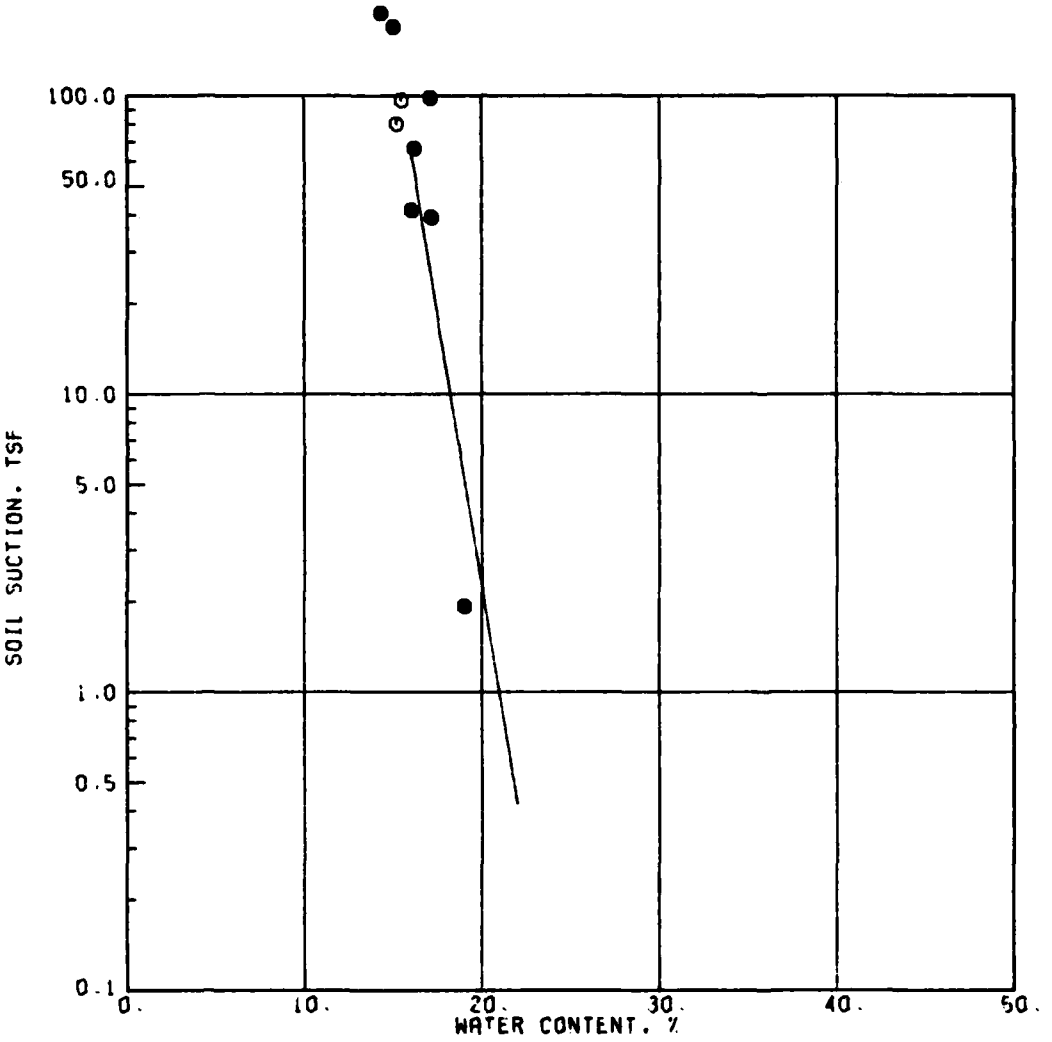
SITE: HOLBROOK, AZ #2
BOR: U-2 SAM: 4 DEP: 6.8-



SOIL SUCTION VERSUS WATER CONTENT RELATIONSHIP USING FILTER PAPER & MCQUEEN/MILLER '68 CALIBRATION CURVE

LOG SOIL SUCTION = 9.2626 -0.4476 * WATER CONTENT

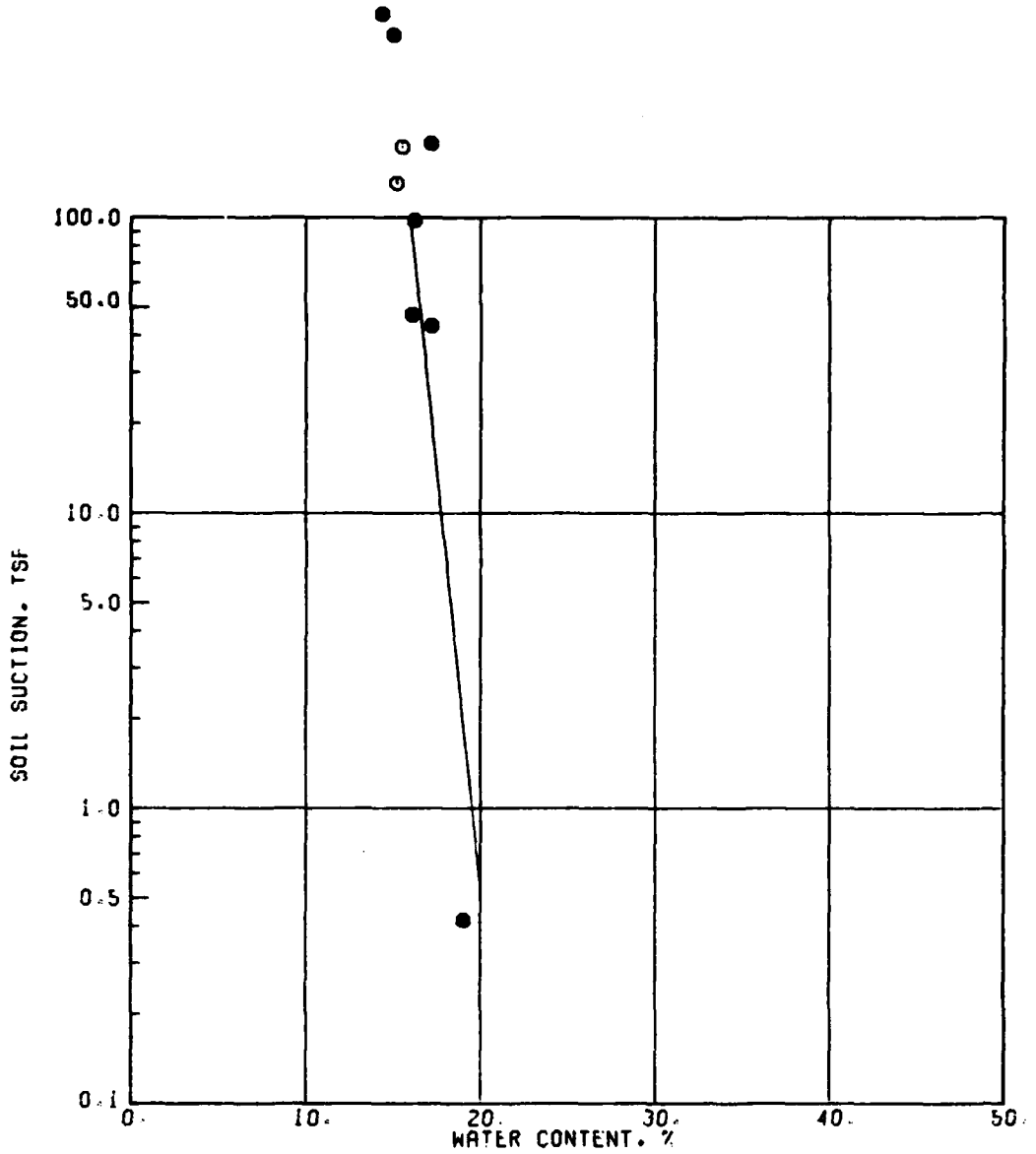
SITE: HOLBROOK, AZ #2
BOR: U-2 SAM: 4 DEP: 6.8-



SOIL SUCTION VERSUS WATER CONTENT RELATIONSHIP USING FILTER PAPER & MILLER '78 CALIBRATION CURVE

LOG SOIL SUCTION = 7.6615 -0.3653 * WATER CONTENT

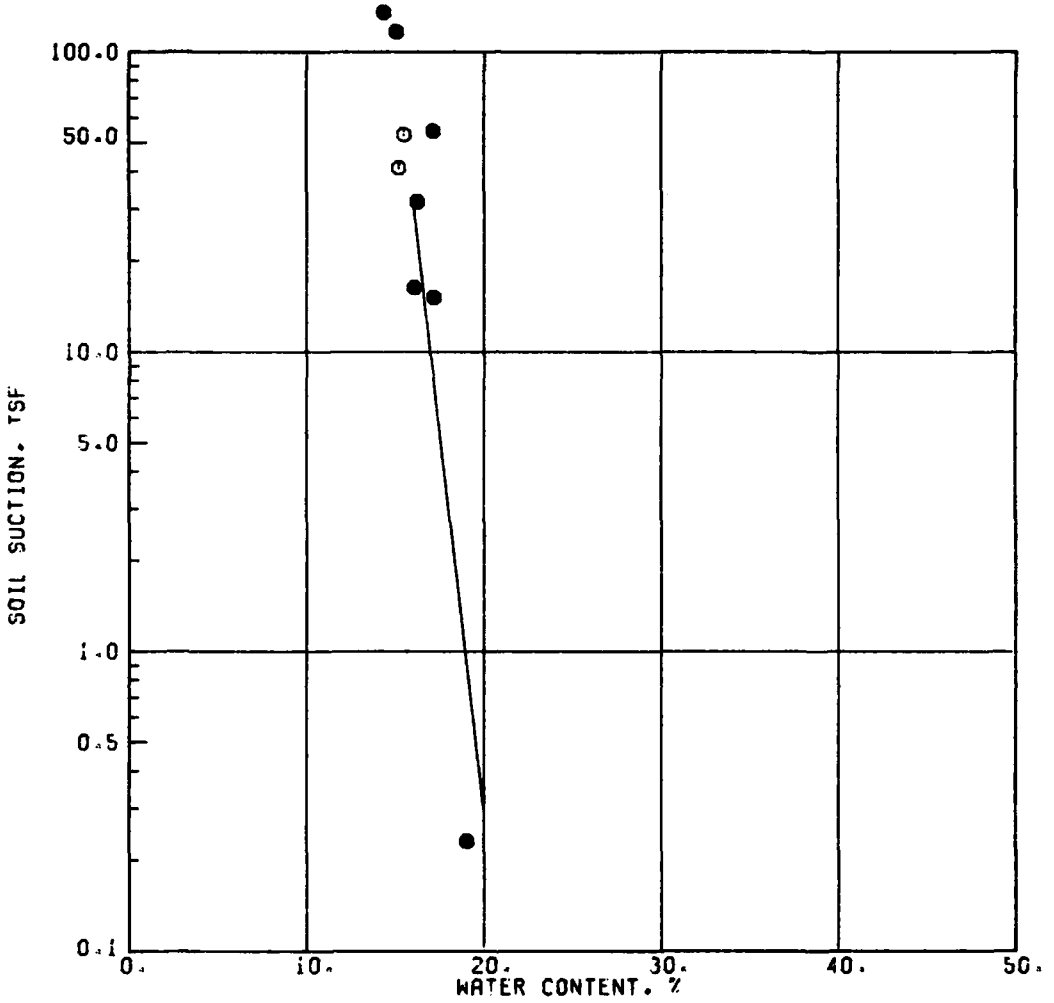
SITE: HOLBROOK, AZ #2
BOR: U-2 SAM: 4 DEP: 6.8-



SOIL SUCTION VERSUS WATER CONTENT RELATIONSHIP USING FILTER PAPER & W.E.S.-I '79 CALIBRATION CURVE

LOG SOIL SUCTION = 10.9946 -0.5634 * WATER CONTENT

SITE: HOLBROOK, AZ #2
BOR: U-2 SAM: 4 DEP: 6.8-



SOIL SUCTION VERSUS WATER CONTENT RELATIONSHIP USING FILTER PAPER & W.E.S.-II '79 CALIBRATION CURVE

LOG SOIL SUCTION = 9.6150 -0.5077 * WATER CONTENT

SITE: HOLBROOK, AZ #2
BOR: U-2 SAM: 4 DEP: 6.8-

- TABLE 1 - SOIL SUCTION AND WATER CONTENT DATA
USING THERMOCOUPLE PSYCHROMETER

SITE: PRICE, UT
BOR: U-2 SAM: 5 DEP: 8.2-10.4 FT

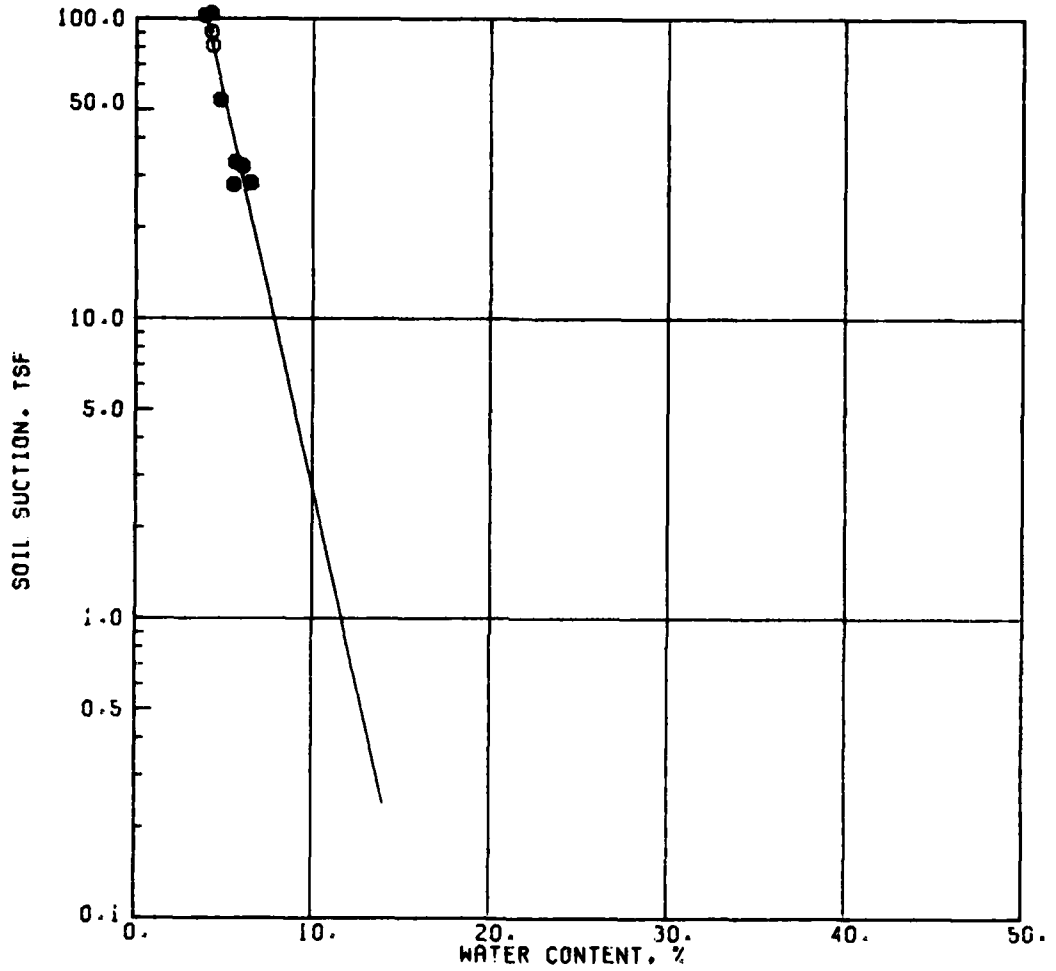
SPECIMEN NUMBER	SOIL SUCTION, TSF	WATER CONTENT %
1	90.3	4.3
2	81.3	4.4
3	53.6	4.8
4	27.9	5.5
5	32.3	6.0
6	33.2	5.6
7	28.4	6.5
8	104.4	4.2
9	102.7	3.9

LOG SOIL SUCTION = 3.0341 -0.2608 * WC

- TABLE 2 - SOIL SUCTION AND WATER CONTENT DATA
USING FILTER PAPER AND CALIBRATION CURVES

SITE: PRICE, UT
BOR: U-2 SAM: 5 DEP: 8.2-10.4 FT

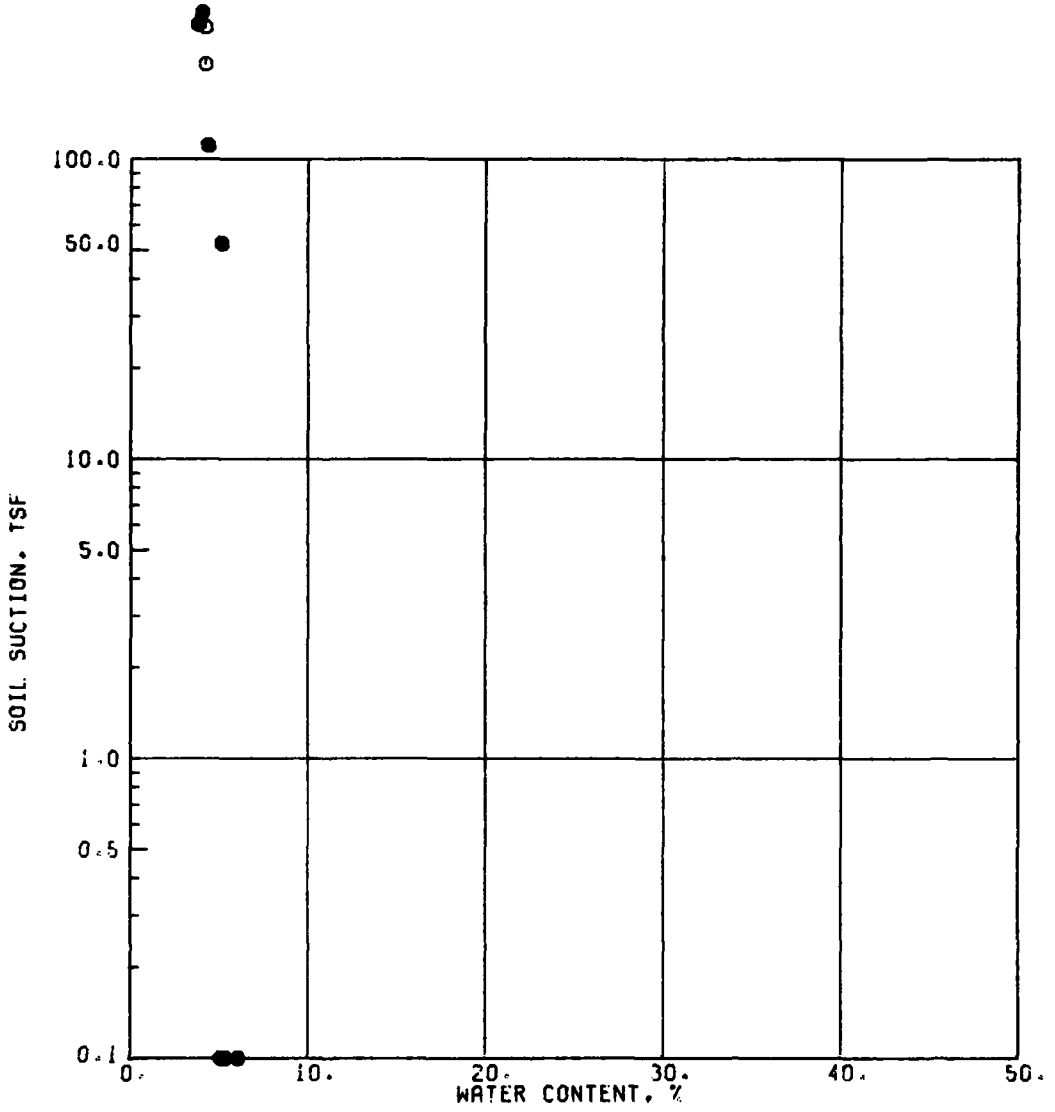
SPECIMEN NUMBER	MOISTURE CONTENT FILTER PAPER %	- - - SOIL SUCTION, TSF - - - McQUEEN/ MILLER 1968	MILLER 1978	W.E.S. I 1979	W.E.S. II 1979	SOIL WATER CONTENT %
1	13.00	207.3	98.4	178.6	54.6	4.24
2	11.28	275.9	124.3	256.1	75.5	4.24
3	16.75	111.0	59.1	81.4	26.9	4.39
4	21.28	52.3	32.0	31.5	11.4	5.15
5	86.57	0.1	0.1	0.1	0.1	5.10
6	138.03	0.1	0.1	0.1	0.1	5.36
7	210.70	0.1	0.1	0.1	0.1	6.09
8	10.61	308.7	136.3	295.0	85.8	4.01
9	11.16	281.4	126.4	262.5	77.2	3.79



SOIL SUCTION VERSUS WATER CONTENT RELATIONSHIP USING THERMOCOUPLE PSYCHROMETERS

LOG SOIL SUCTION = 3.0341 -0.2608 * WATER CONTENT

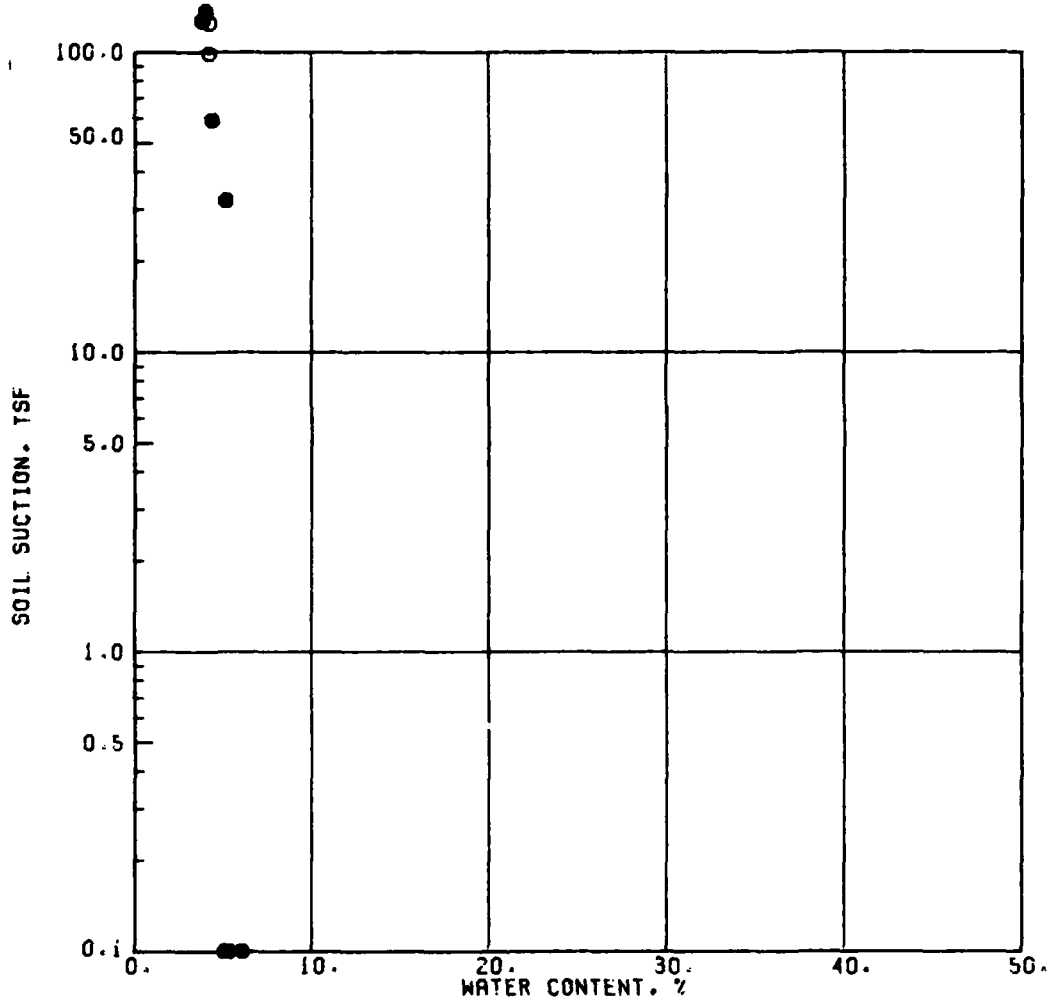
SITE: PRICE, UT
BOR: U-2 SAM: 5 DEP: 8.2-



SOIL SUCTION VERSUS WATER CONTENT RELATIONSHIP USING FILTER PAPER & MCQUEEN/MILLER '68 CALIBRATION CURVE

LOG SOIL SUCTION = 9.9730 -1.8717 * WATER CONTENT

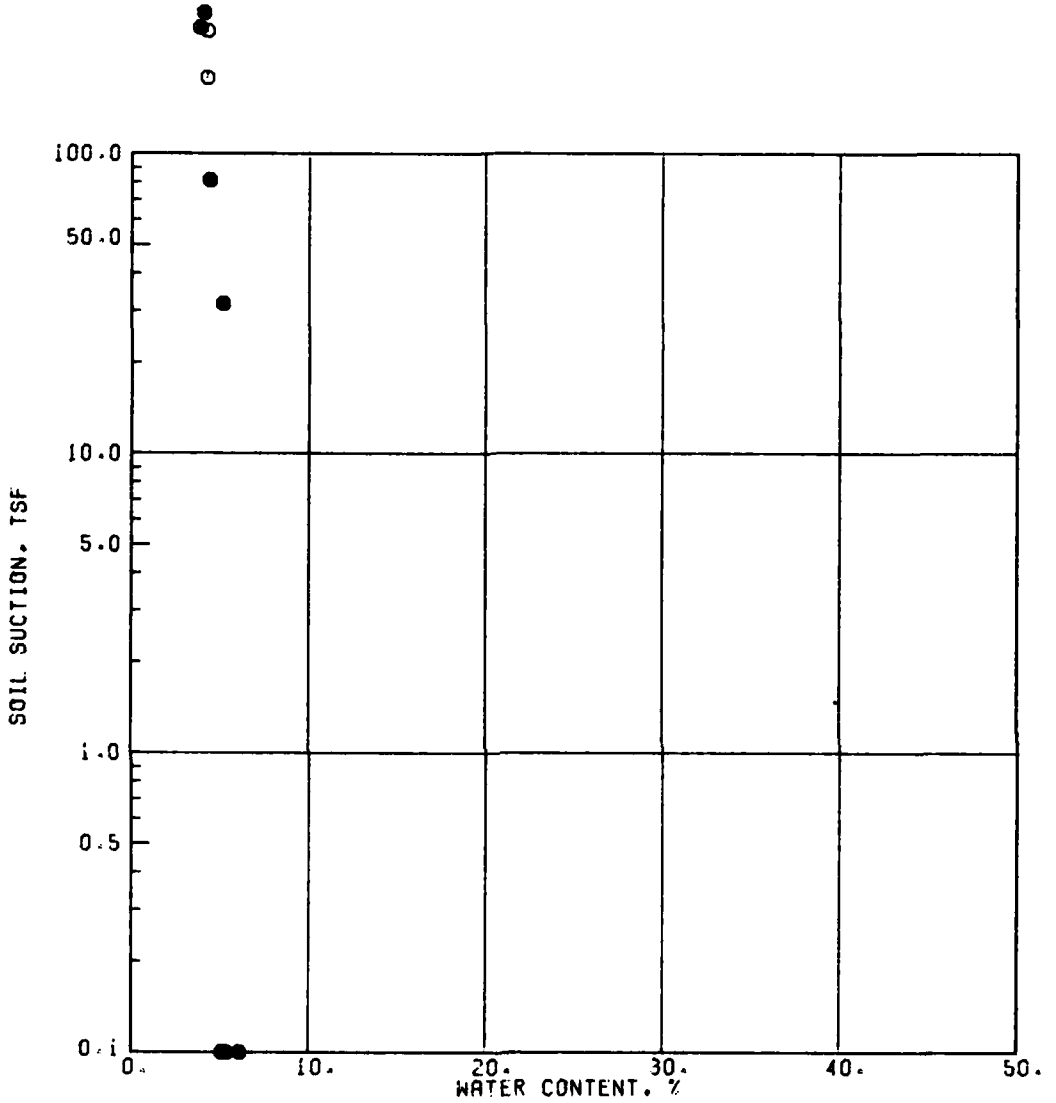
SITE: PRICE, UT
BOR: U-2 SAM: 5 DEP: 8.2-



SOIL SUCTION VERSUS WATER CONTENT RELATIONSHIP USING FILTER PAPER & MILLER '78 CALIBRATION CURVE

LOG SOIL SUCTION = 8.8645 -1.6801 * WATER CONTENT

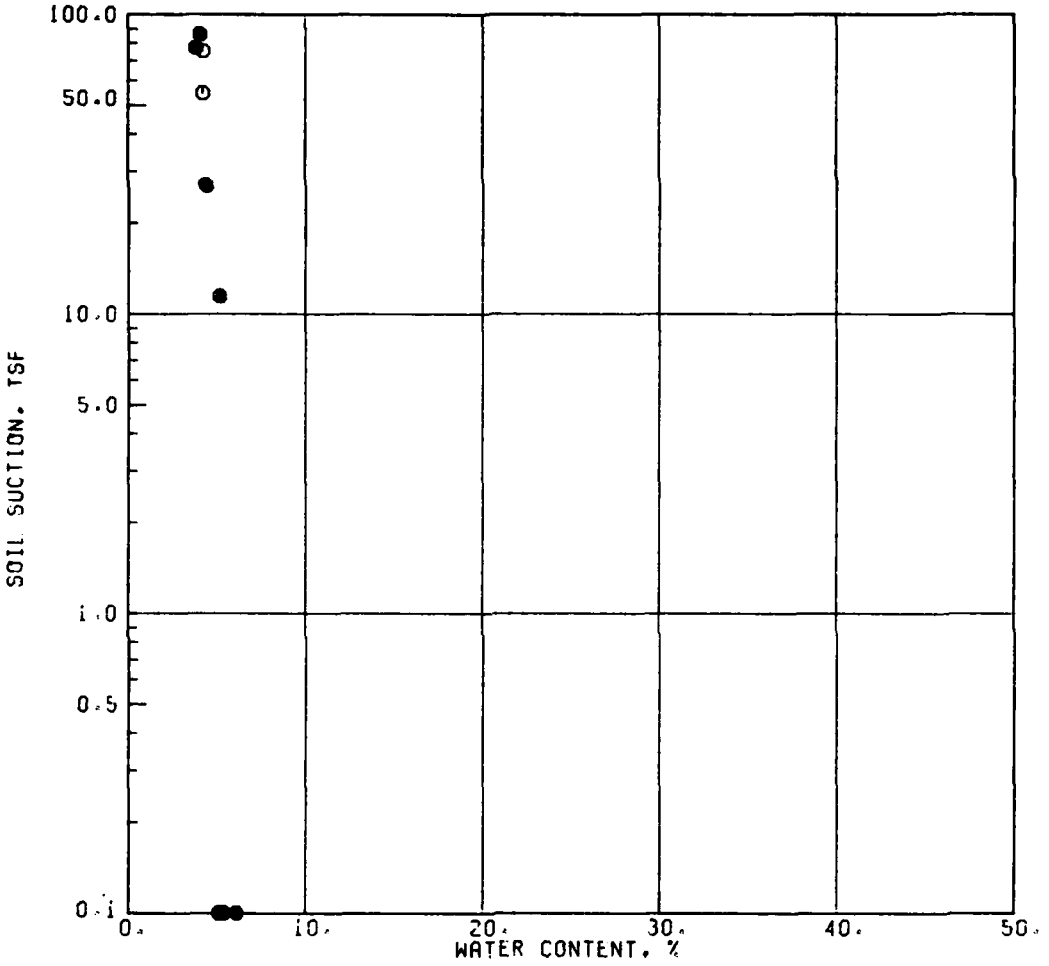
SITE: PRICE, UT
BOR: U-2 SAM: 5 DEP: 8.2-



SOIL SUCTION VERSUS WATER CONTENT RELATIONSHIP USING FILTER PAPER & W.E.S.-I '79 CALIBRATION CURVE

LOG SOIL SUCTION = 9.6842 -1.8647 * WATER CONTENT

SITE: PRICE, UT
BOR: U-2 SAM: 5 DEP: 8.2-



SOIL SUCTION VERSUS WATER CONTENT RELATIONSHIP USING FILTER PAPER & W.E.S.-II '79 CALIBRATION CURVE

LOG SOIL SUCTION = 8.1941 -1.5773 * WATER CONTENT

SITE: PRICE, UT
BOR: U-2 SAM: 5 DEP: 8.2-

- TABLE 1 - SOIL SUCTION AND WATER CONTENT DATA USING THERMOCOUPLE PSYCHROMETER

SITE: HAYES, KS
BOR: U-2 SAM: 4 DEP: 6.4-8.5 FT

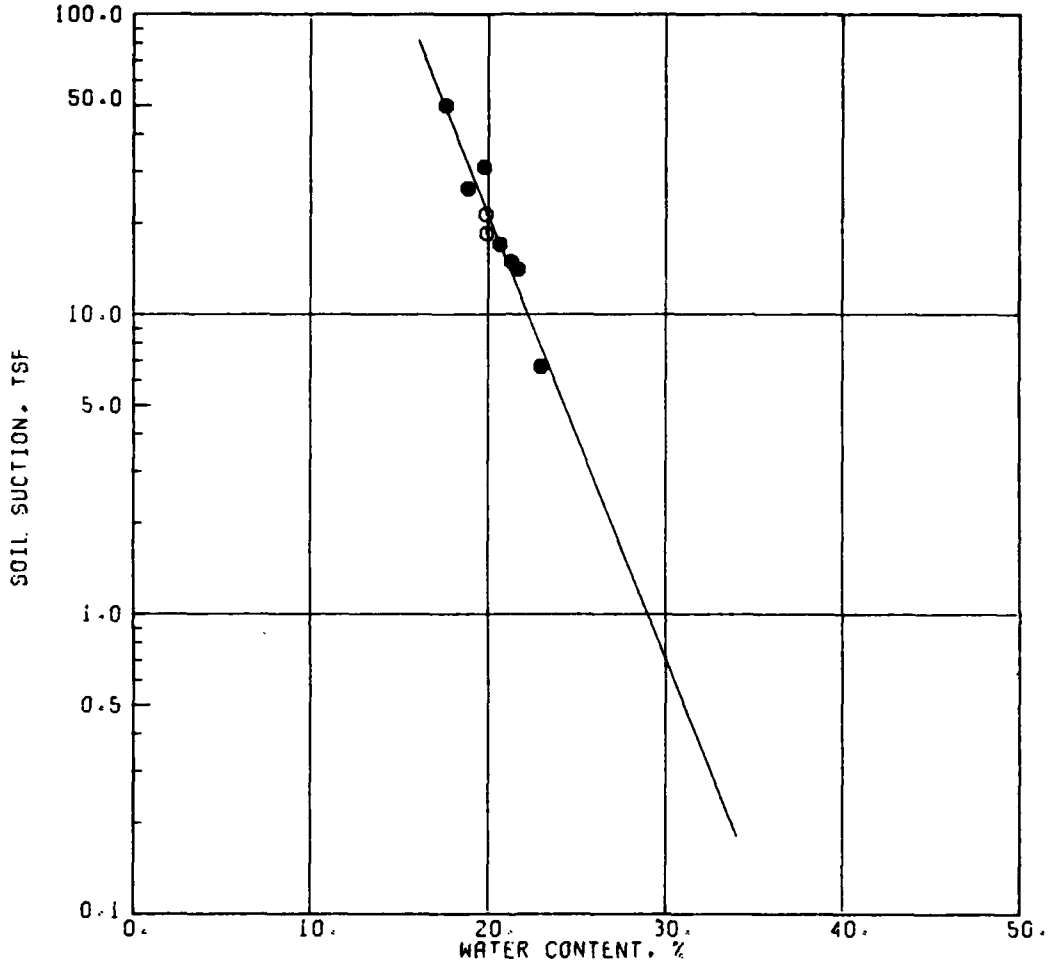
SPECIMEN NUMBER	SOIL SUCTION, TSF	WATER CONTENT %
1	18.5	19.9
2	21.4	19.9
3	17.1	20.7
4	14.1	21.7
5	14.9	21.3
6	6.7	22.9
7	26.3	18.8
8	30.9	19.7
9	49.7	17.6

LOG SOIL SUCTION = 4.2837 -0.1478 * WC

- TABLE 2 - SOIL SUCTION AND WATER CONTENT DATA USING FILTER PAPER AND CALIBRATION CURVES

SITE: HAYES, KS
BOR: U-2 SAM: 4 DEP: 6.4-8.5 FT

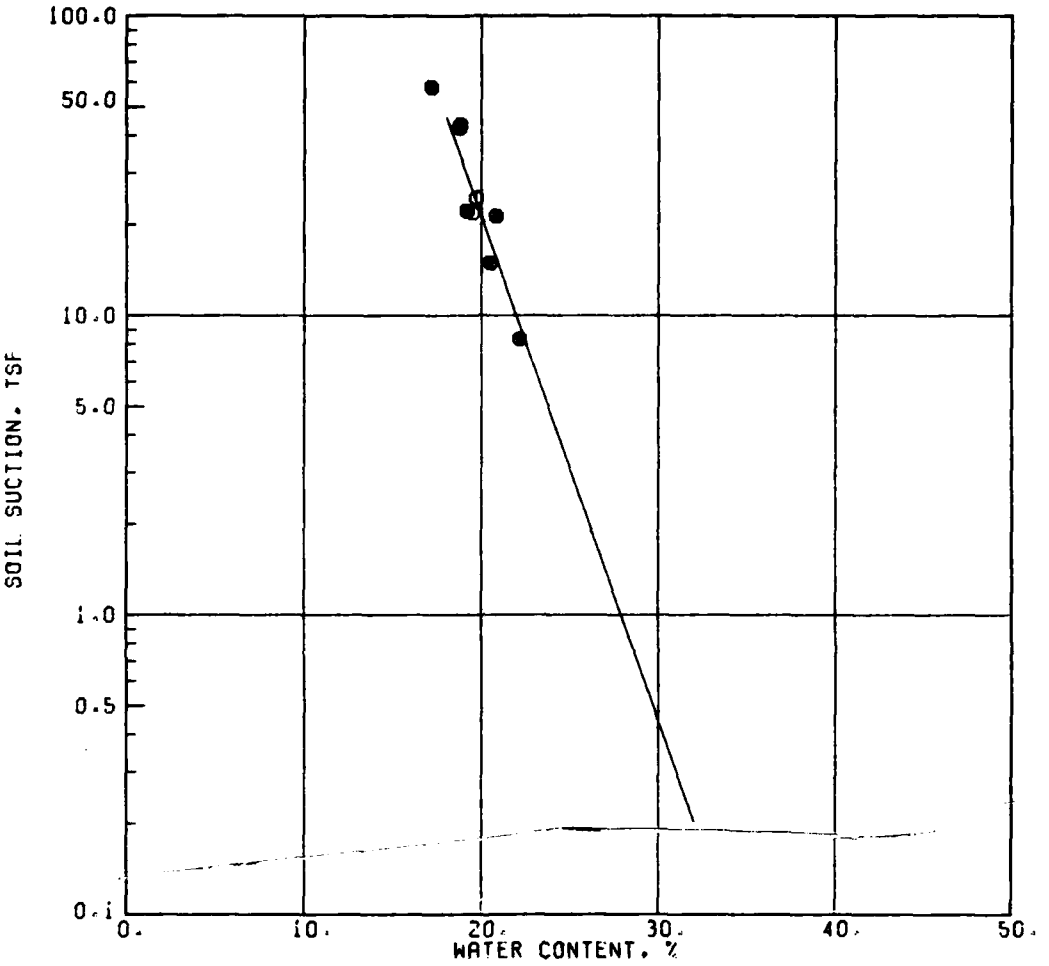
SPECIMEN NUMBER	MOISTURE CONTENT FILTER PAPER %	- - - SOIL SUCTION, TSF - - - McQUEEN/ MILLER 1968	MILLER 1978	W.E.S. I 1979	W.E.S. II 1979	SOIL WATER CONTENT %
1	25.79	24.6	17.3	12.2	4.9	19.74
2	26.48	22.0	15.8	10.6	4.3	19.53
3	26.40	22.3	16.0	10.8	4.4	19.19
4	26.63	21.4	15.4	10.3	4.2	20.33
5	28.80	14.9	11.5	6.5	2.8	20.48
6	32.31	8.3	7.1	3.1	1.4	22.15
7	22.56	42.2	26.8	24.1	9.0	18.75
8	22.40	43.4	27.5	24.9	9.3	18.82
9	20.69	57.6	34.6	35.7	12.8	17.16



SOIL SUCTION VERSUS WATER CONTENT RELATIONSHIP USING THERMOCOUPLE PSYCHROMETERS

LOG SOIL SUCTION = 4.2837 -0.1478 * WATER CONTENT

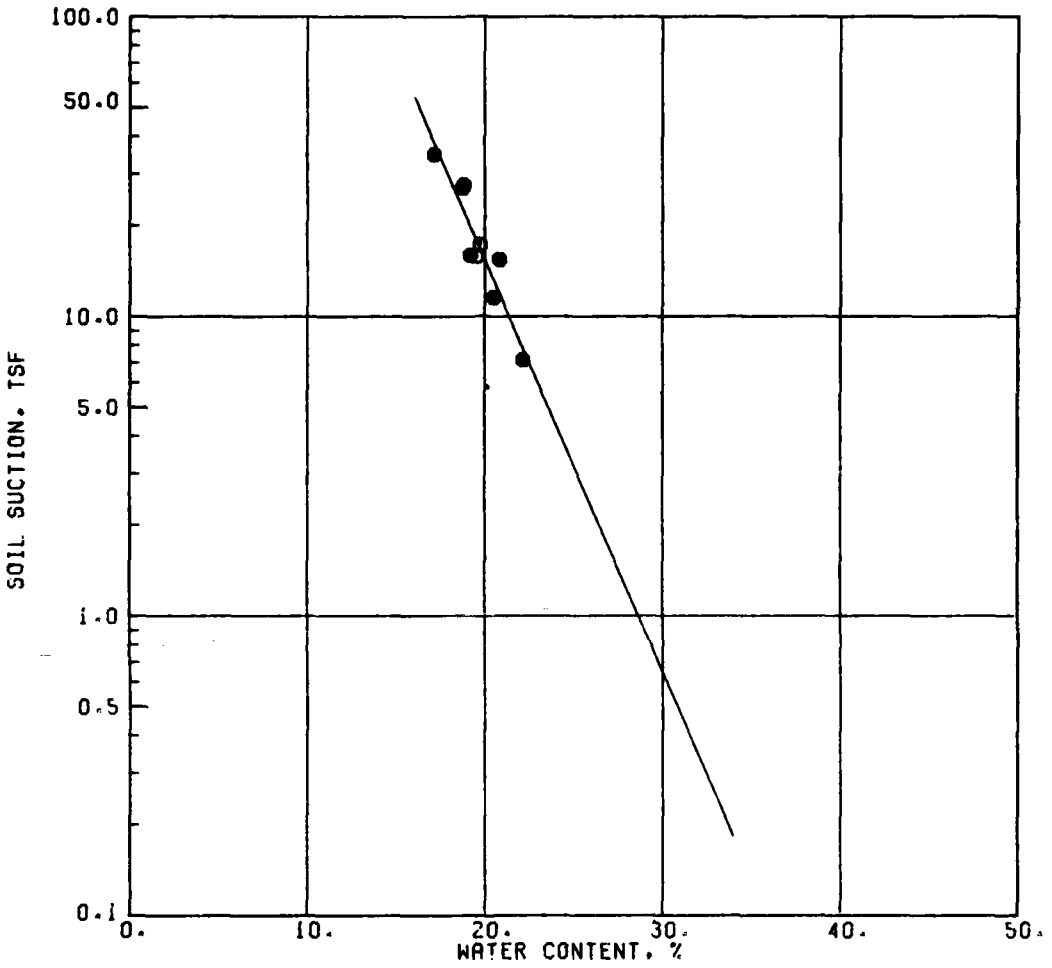
SITE: HAYES, KS
BOR: U-2 SAM: 4 DEP: 6.4-



SOIL SUCTION VERSUS WATER CONTENT RELATIONSHIP USING FILTER PAPER & MCQUEEN/MILLER '68 CALIBRATION CURVE

LOG SOIL SUCTION = 4.6978 -0.1684 * WATER CONTENT

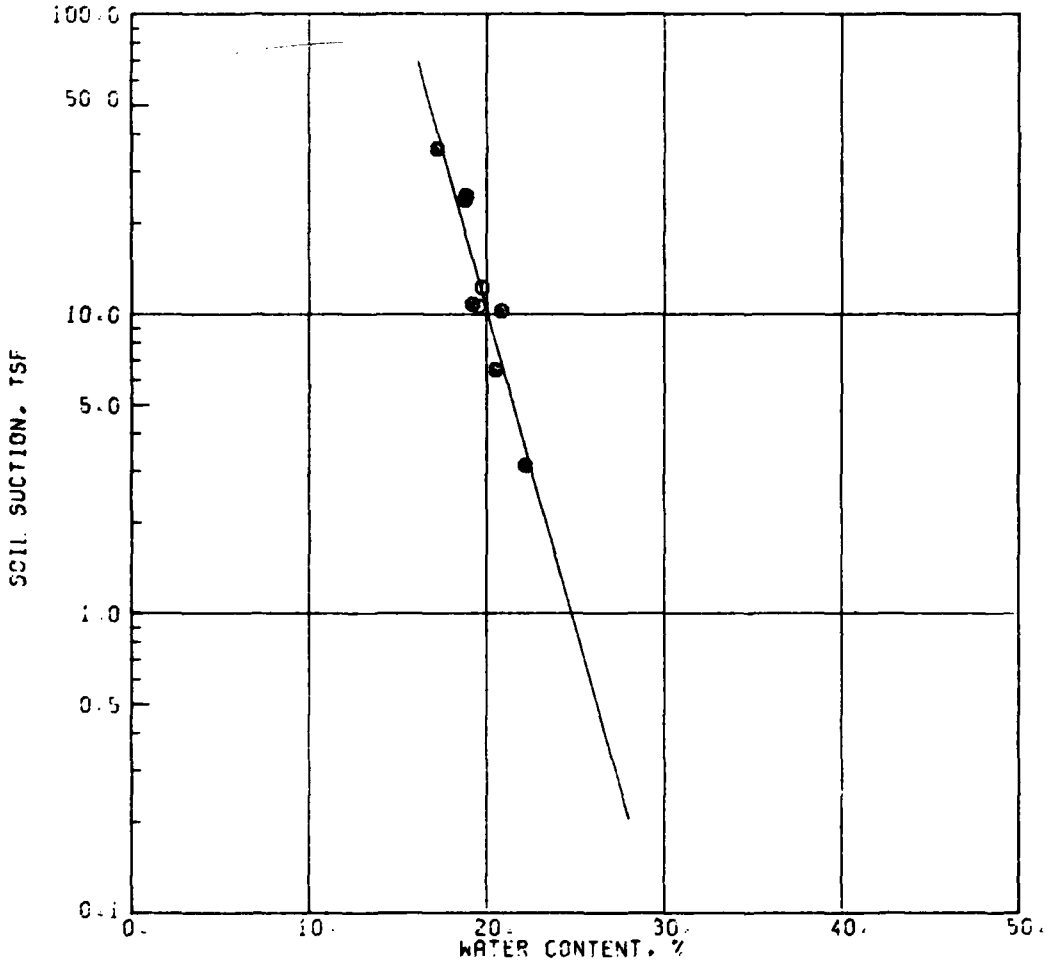
SITE: HAYES, KS
BOR: U-2 SAM: 4 DEP: 6.4-



SOIL SUCTION VERSUS WATER CONTENT RELATIONSHIP USING FILTER PAPER & MILLER '78 CALIBRATION CURVE

LOG SOIL SUCTION = 3.9364 -0.1374 * WATER CONTENT

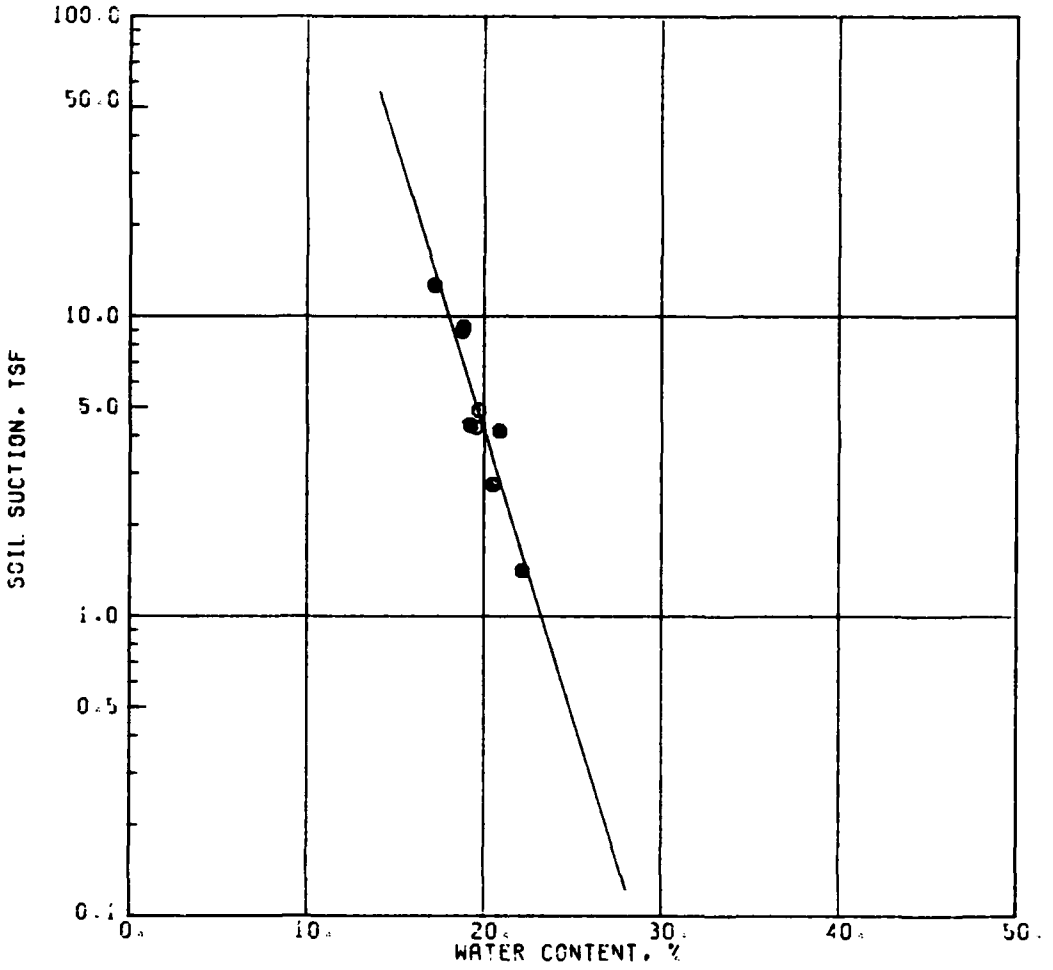
SITE: HAYES, KS
BOR: U-2 SAM: 4 DEP: 6.4-



SOIL SUCTION VERSUS WATER CONTENT RELATIONSHIP USING FILTER PAPER & W.E.S.-I '79 CALIBRATION CURVE

LOG SOIL SUCTION = 5.2492 -0.2120 * WATER CONTENT

SITE: HAYES, KS
BOR: U-2 SAM: 4 DEP: 6.4-



SOIL SUCTION VERSUS WATER CONTENT RELATIONSHIP USING FILTER PAPER & W.E.S.-II '79 CALIBRATION CURVE

LOG SOIL SUCTION = 4.4377 -0.1910 * WATER CONTENT

SITE: HAYES, KS
BOR: U-2 SAM: 4 DEP: 6.4-

- TABLE 1 - SOIL SUCTION AND WATER CONTENT DATA USING THERMOCOUPLE PSYCHROMETER

SITE: ELLSWORTH, KS
BOR: U-2 SAM: 3 DEP: 6.0-7.9 FT

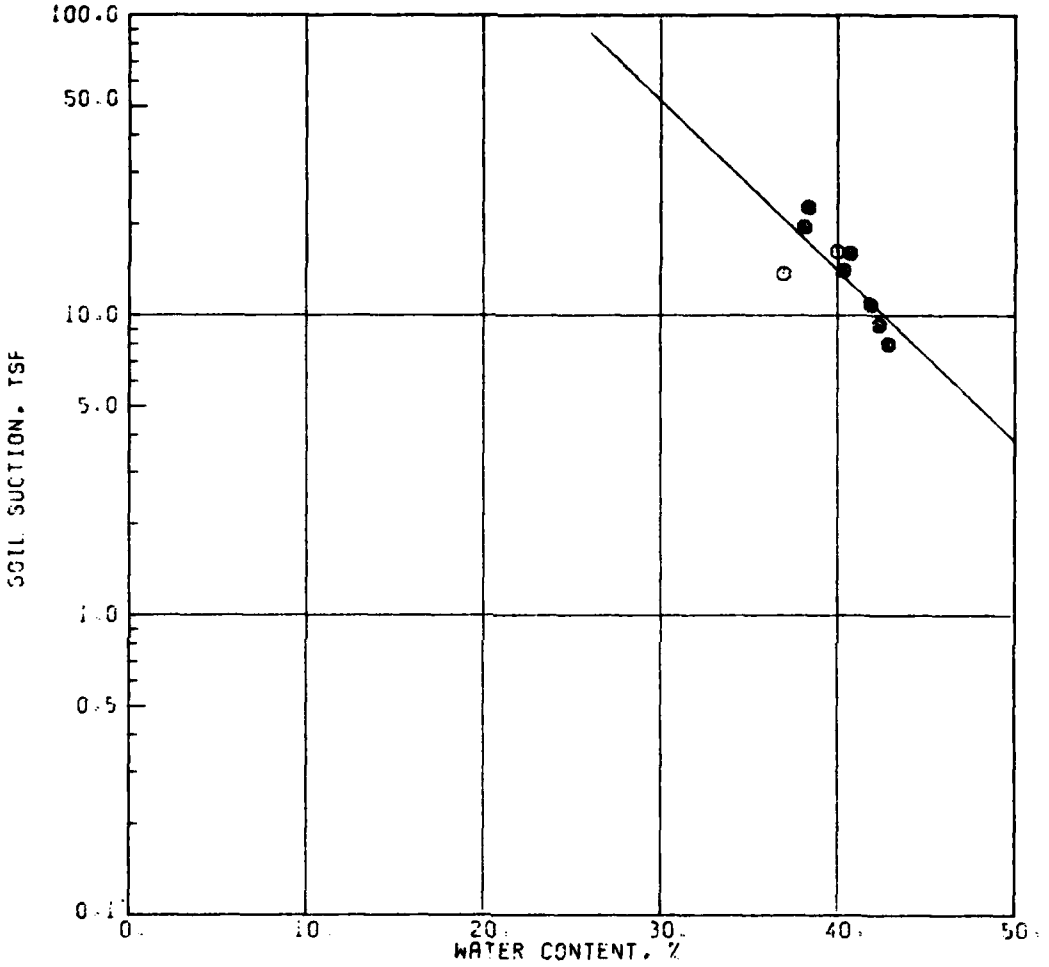
SPECIMEN NUMBER	SOIL SUCTION, TSF	WATER CONTENT %
1	16.3	39.9
2	13.8	36.9
3	16.1	40.7
4	9.3	42.3
5	10.9	41.9
6	8.0	42.9
7	14.1	40.3
8	19.7	38.1
9	22.9	38.3

LOG SOIL SUCTION = 3.4202 -0.0568 * WC

- TABLE 2 - SOIL SUCTION AND WATER CONTENT DATA USING FILTER PAPER AND CALIBRATION CURVES

SITE: ELLSWORTH, KS
BOR: U-2 SAM: 3 DEP: 6.0-7.9 FT

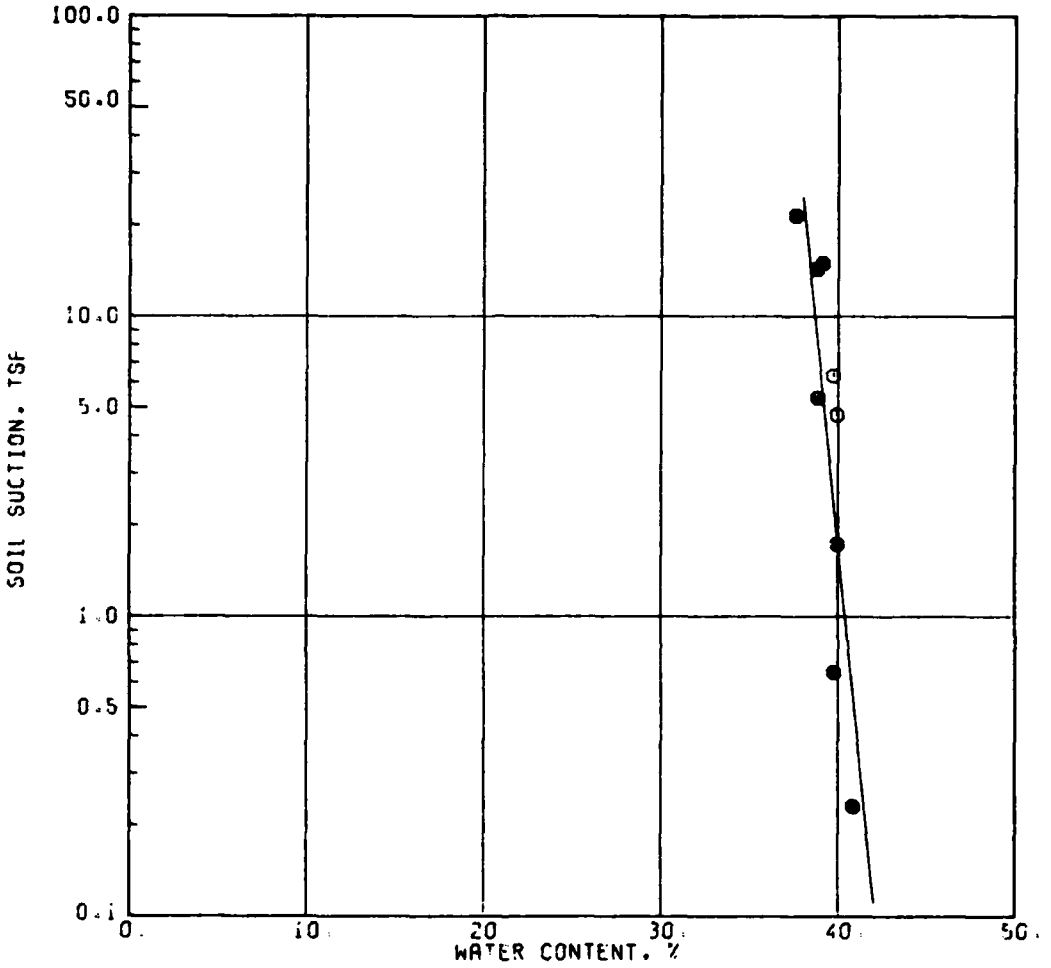
SPECIMEN NUMBER	MOISTURE CONTENT FILTER PAPER %	- - - SOIL SUCTION, TSF - - - McQUEEN/ MILLER 1968	MILLER 1978	W.E.S. I 1979	W.E.S. II 1979	SOIL WATER CONTENT %
1	35.75	4.7	4.5	1.5	0.7	39.92
2	33.95	6.3	5.7	2.2	1.0	39.73
3	34.98	5.3	5.0	1.8	0.9	38.84
4	41.71	1.7	2.0	0.4	0.2	39.92
5	47.62	0.7	0.9	0.1	0.1	39.74
6	53.81	0.2	0.4	0.1	0.1	40.83
7	29.05	14.3	11.1	6.2	2.6	38.76
8	28.77	15.0	11.5	6.6	2.8	39.10
9	26.57	21.6	15.6	10.4	4.2	37.60



SOIL SUCTION VERSUS WATER CONTENT RELATIONSHIP USING THERMOCOUPLE PSYCHROMETERS

LOG SOIL SUCTION = 3.4202 -0.0568 * WATER CONTENT

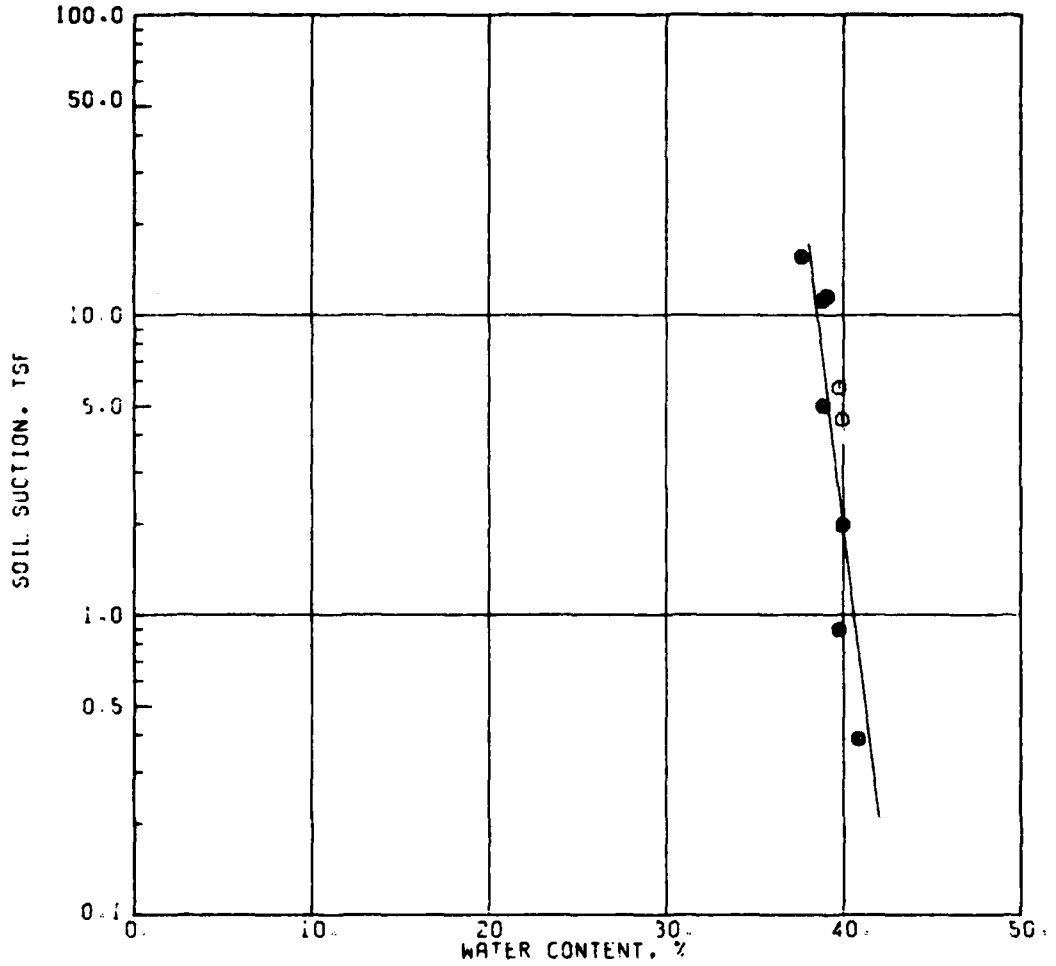
SITE: ELLSWORTH, KS
BOR: U-2 SAM: 3 DEP: 6.0-



SOIL SUCTION VERSUS WATER CONTENT RELATIONSHIP USING FILTER PAPER & MCQUEEN/MILLER '68 CALIBRATION CURVE

LOG SOIL SUCTION = 23.7498 -0.5882 * WATER CONTENT

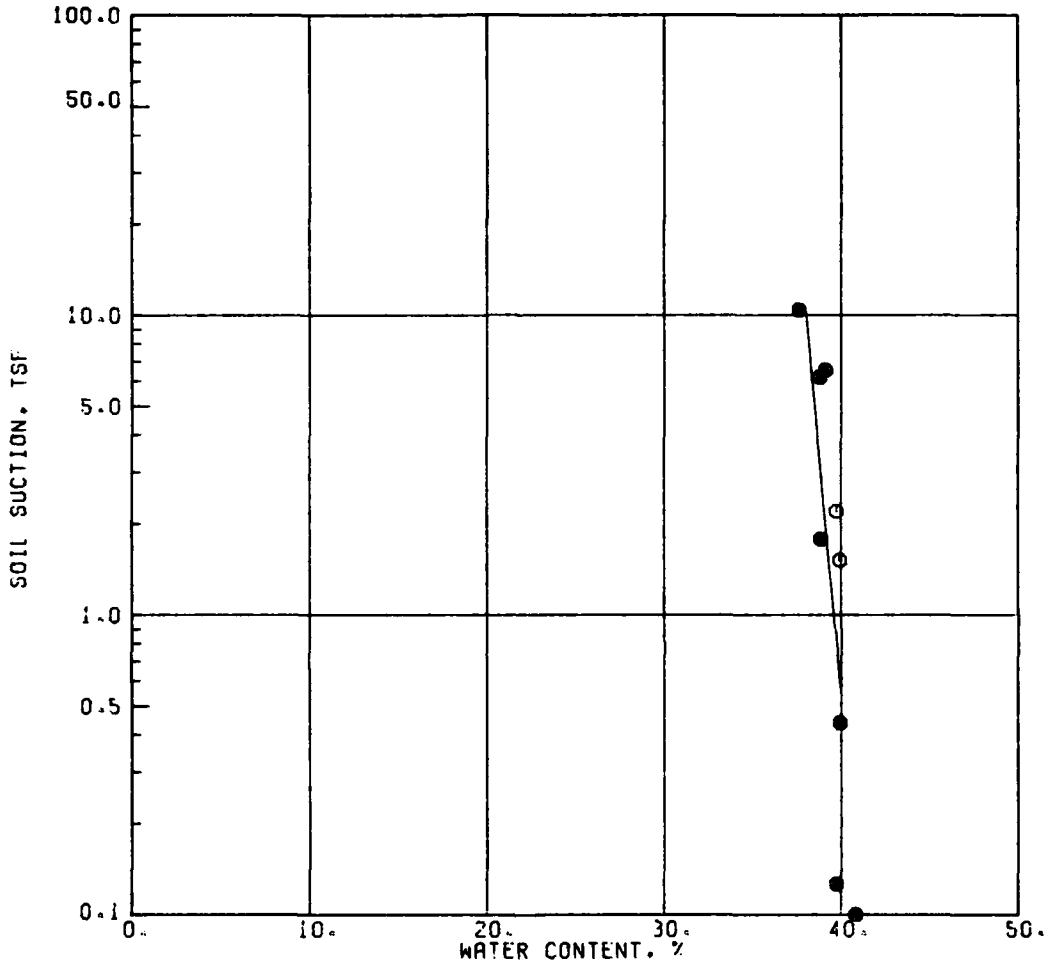
SITE: ELLSWORTH, KS
BOR: U-2 SAM: 3 DEP: 6.0-



SOIL SUCTION VERSUS WATER CONTENT RELATIONSHIP USING FILTER PAPER & MILLER '78 CALIBRATION CURVE

LOG SOIL SUCTION = 19.4837 -0.4800 * WATER CONTENT

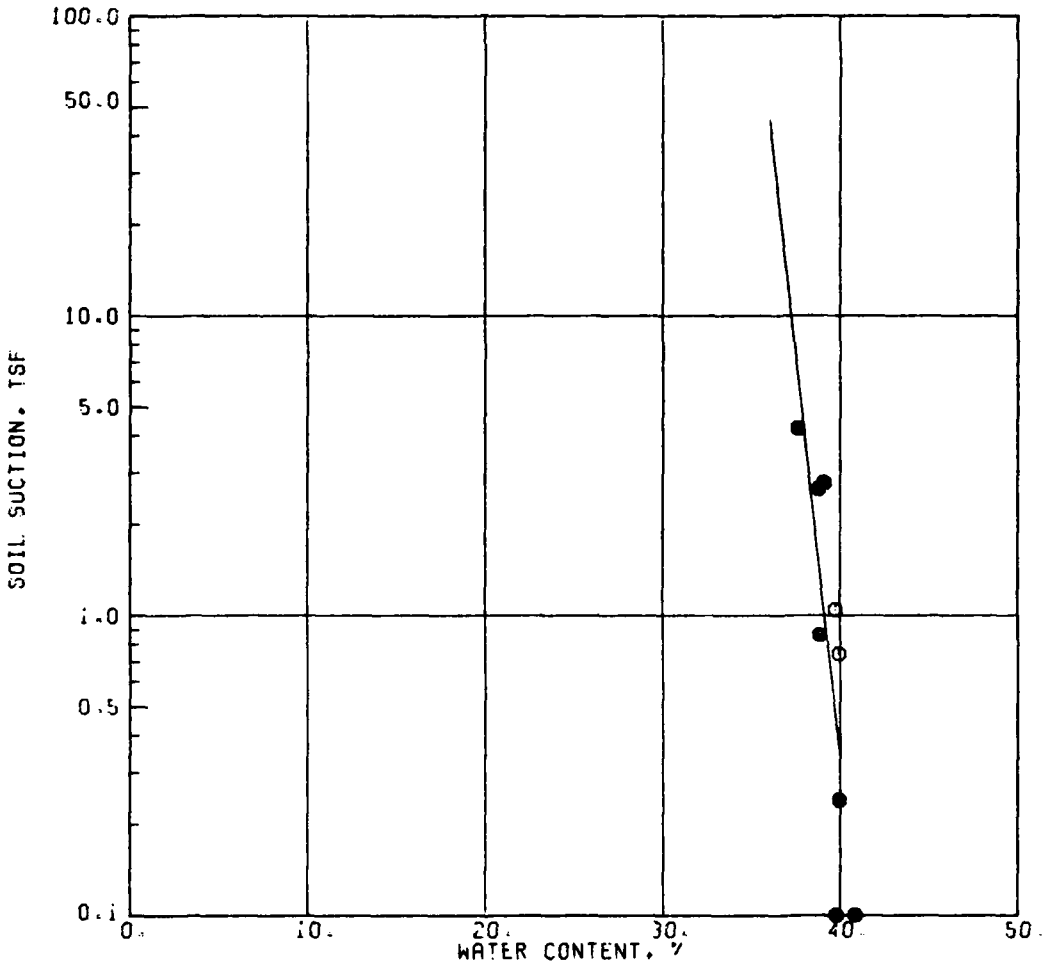
SITE: ELLSWORTH, KS
BOR: U-2 SAM: 3 DEP: 6.0-



SOIL SUCTION VERSUS WATER CONTENT RELATIONSHIP USING FILTER PAPER & W.E.S.-I '79 CALIBRATION CURVE

LOG SOIL SUCTION = 25.4478 -0.6430 * WATER CONTENT

SITE: ELLSWORTH, KS
BOR: U-2 SAM: 3 DEP: 6.0-



SOIL SUCTION VERSUS WATER CONTENT RELATIONSHIP USING FILTER PAPER & W.E.S.-II '79 CALIBRATION CURVE

LOG SOIL SUCTION = 20.8580 -0.5333 * WATER CONTENT

SITE: ELLSWORTH, KS
BOR: U-2 SAM: 3 DEP: 6.0-

- TABLE 1 - SOIL SUCTION AND WATER CONTENT DATA USING THERMOCOUPLE PSYCHROMETER

SITE: LIMON, CO #1
BOR: U-2 SAM: 4 DEP: 7.4-8.8 FT

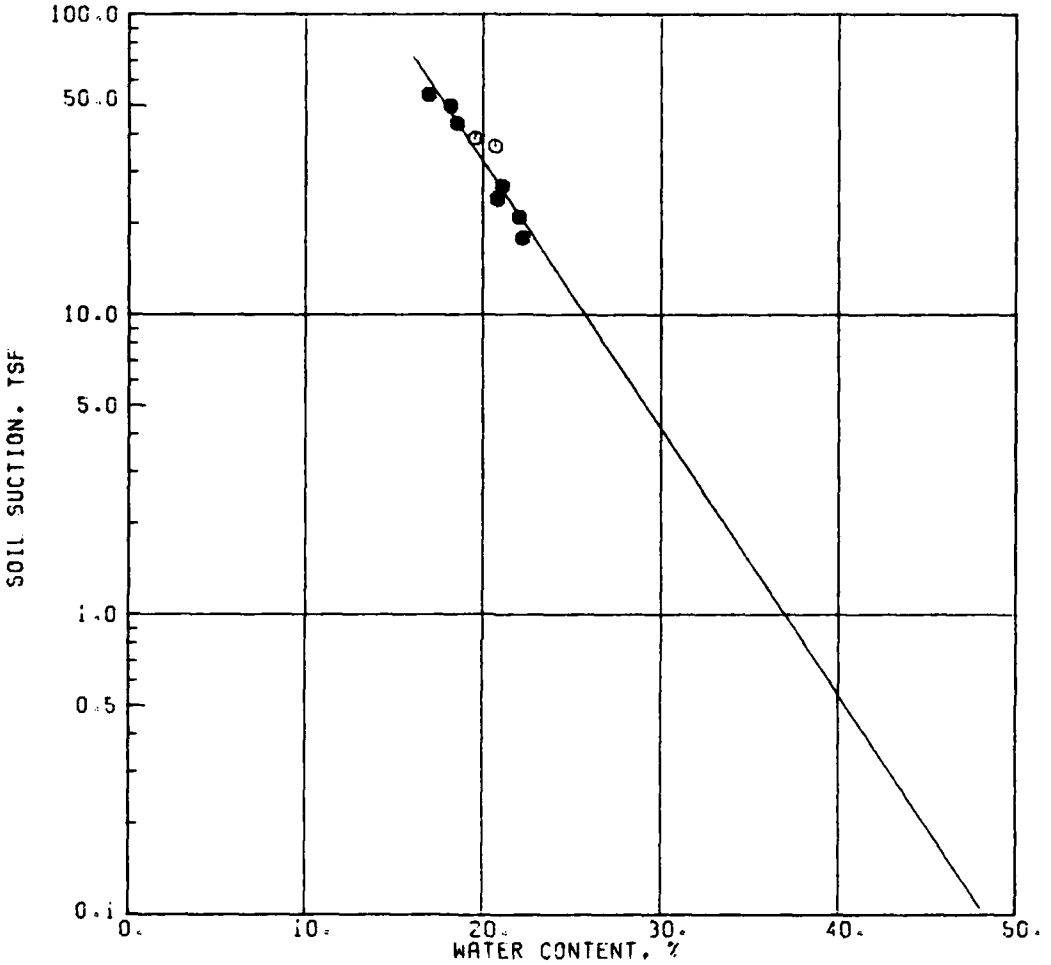
SPECIMEN NUMBER	SOIL SUCTION, TSF	WATER CONTENT %
1	38.5	19.5
2	36.3	20.7
3	24.2	20.8
4	26.7	21.0
5	17.9	22.2
6	21.1	22.0
7	43.3	18.5
8	49.6	18.1
9	54.1	16.9

LOG SOIL SUCTION = 3.2847 -0.0888 * WC

- TABLE 2 - SOIL SUCTION AND WATER CONTENT DATA USING FILTER PAPER AND CALIBRATION CURVES

SITE: LIMON, CO #1
BOR: U-2 SAM: 4 DEP: 7.4-8.8 FT

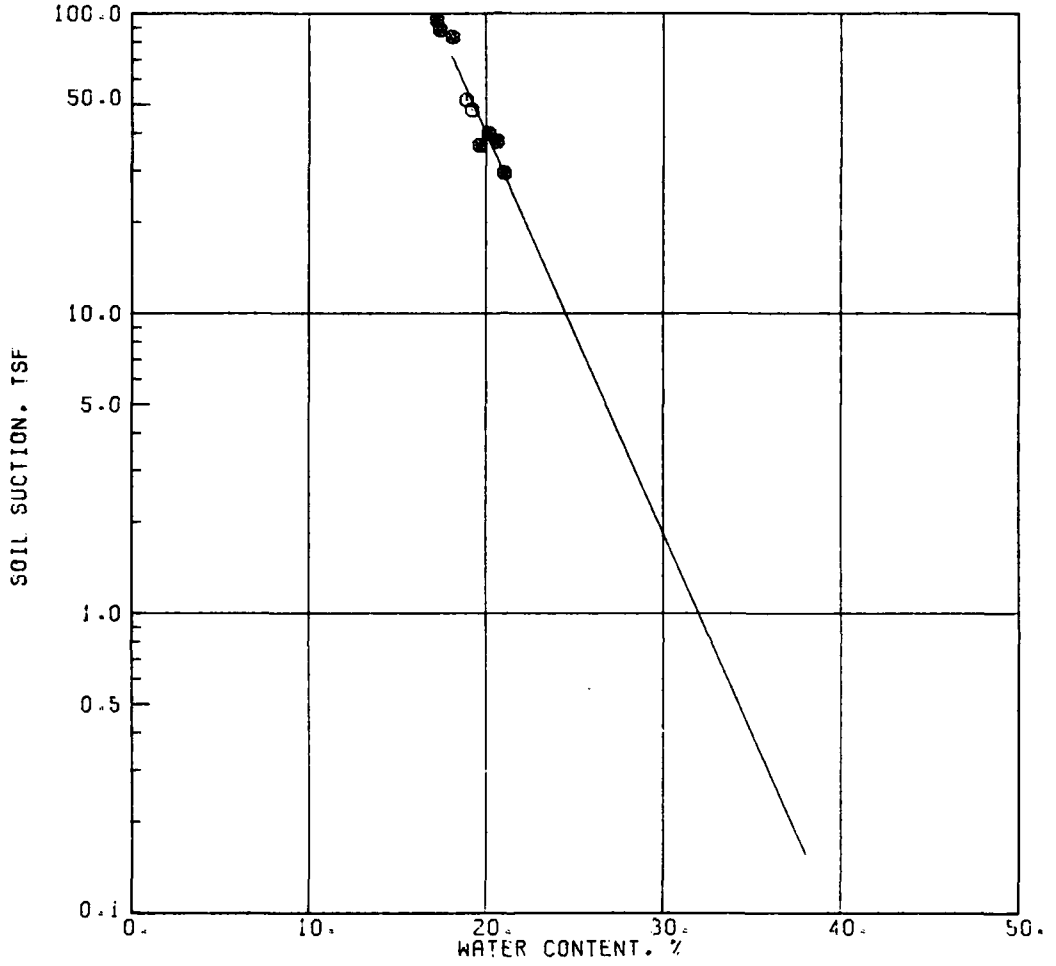
SPECIMEN NUMBER	MOISTURE CONTENT FILTER PAPER %	- - - SOIL SUCTION, TSF - - - McQUEEN/ MILLER 1968	MILLER 1978	W.E.S. I 1979	W.E.S. II 1979	SOIL WATER CONTENT %
1	21.40	51.2	31.5	30.8	11.2	18.89
2	21.84	47.5	29.6	28.0	10.3	19.18
3	23.47	36.2	23.7	19.9	7.6	19.61
4	22.93	39.7	25.6	22.3	8.4	20.13
5	23.30	37.3	24.3	20.6	7.8	20.61
6	24.75	29.3	20.0	15.2	5.9	21.03
7	18.14	88.1	49.0	60.9	20.7	17.38
8	18.48	83.2	46.7	56.6	19.4	18.09
9	17.70	94.7	52.0	66.7	22.5	17.21



SOIL SUCTION VERSUS WATER CONTENT RELATIONSHIP USING THERMOCOUPLE PSYCHROMETERS

LOG SOIL SUCTION = 3.2847 -0.0888 * WATER CONTENT

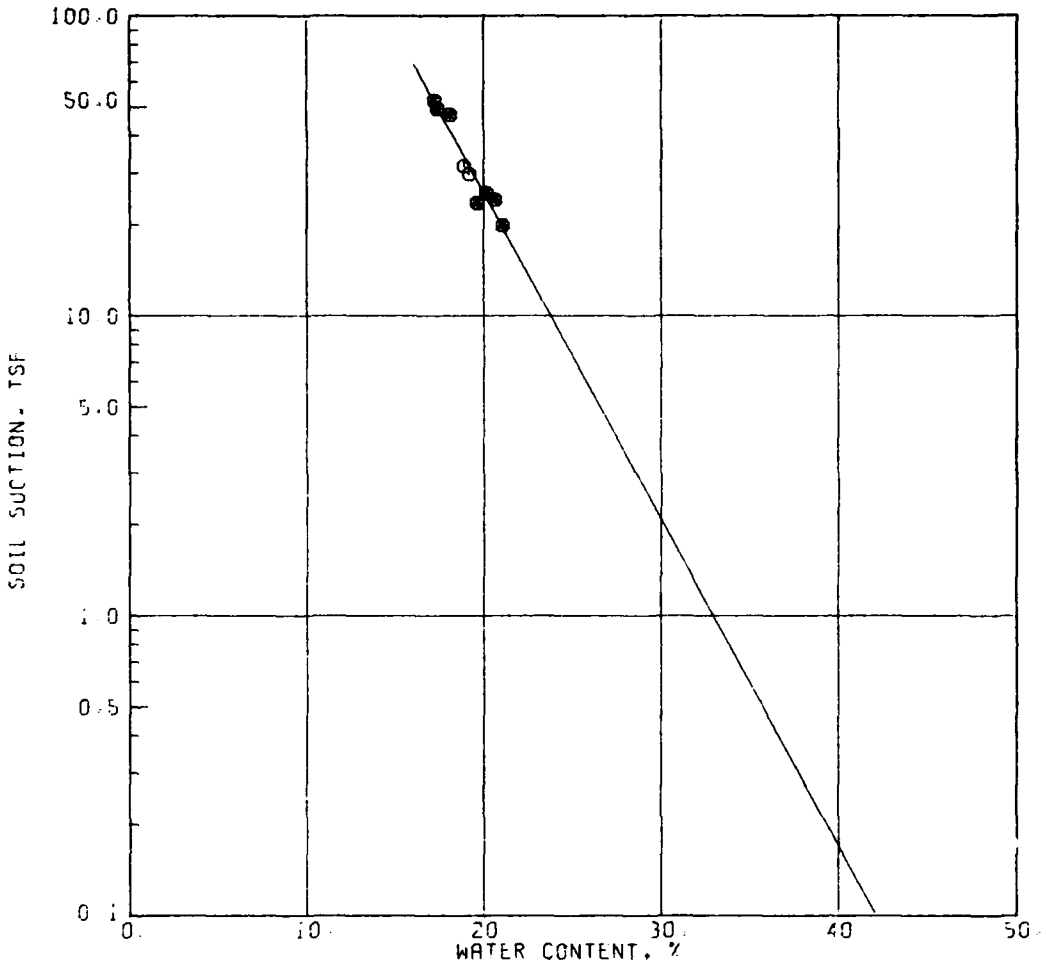
SITE: LIMON, CO #1
BOR: U-2 SAM: 4 DEP: 7.4-



SOIL SUCTION VERSUS WATER CONTENT RELATIONSHIP USING FILTER PAPER & MCQUEEN/MILLER '68 CALIBRATION CURVE

LOG SOIL SUCTION = 4.2655 -0.1334 * WATER CONTENT

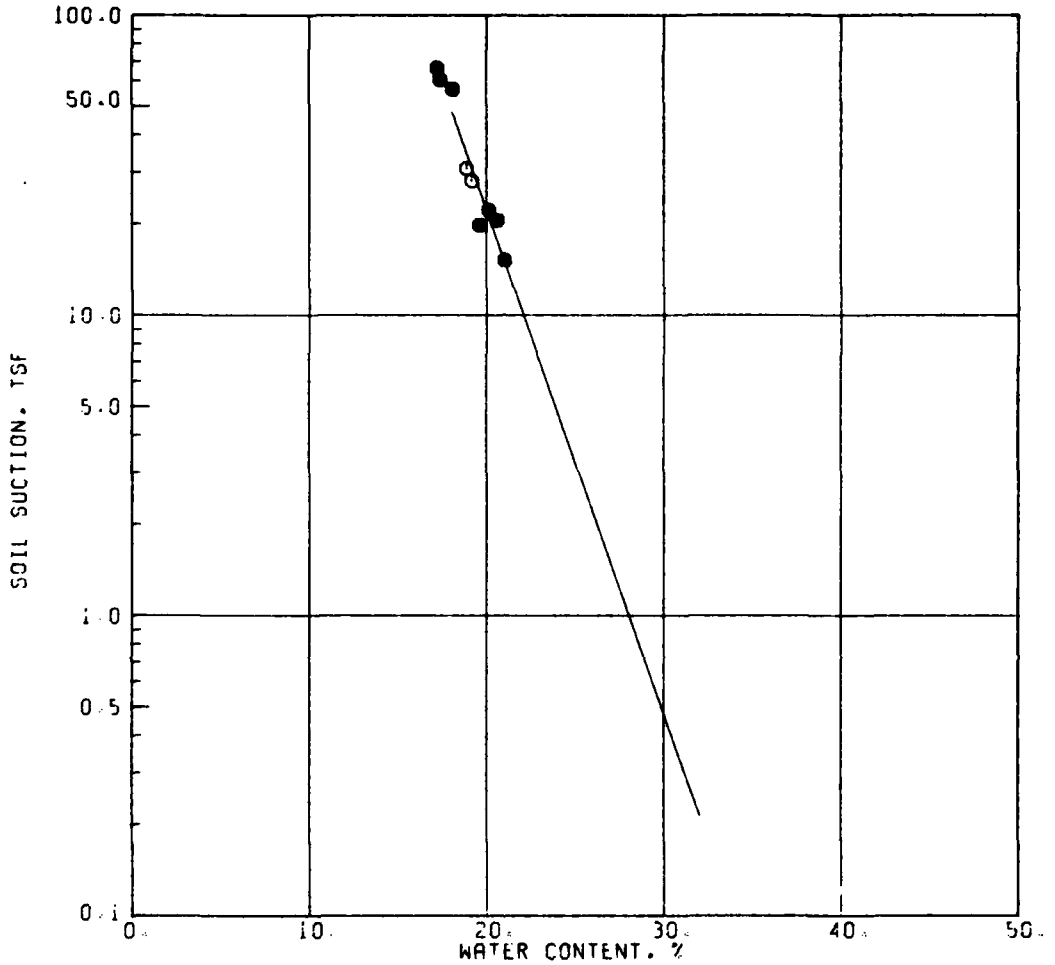
SITE: LIMON, CO #1
BOR: U-2 SAM: 4 DEP: 7.4-



SOIL SUCTION VERSUS WATER CONTENT RELATIONSHIP USING FILTER PAPER & MILLER '78 CALIBRATION CURVE

LOG SOIL SUCTION = 3.5837 -0.1089 * WATER CONTENT

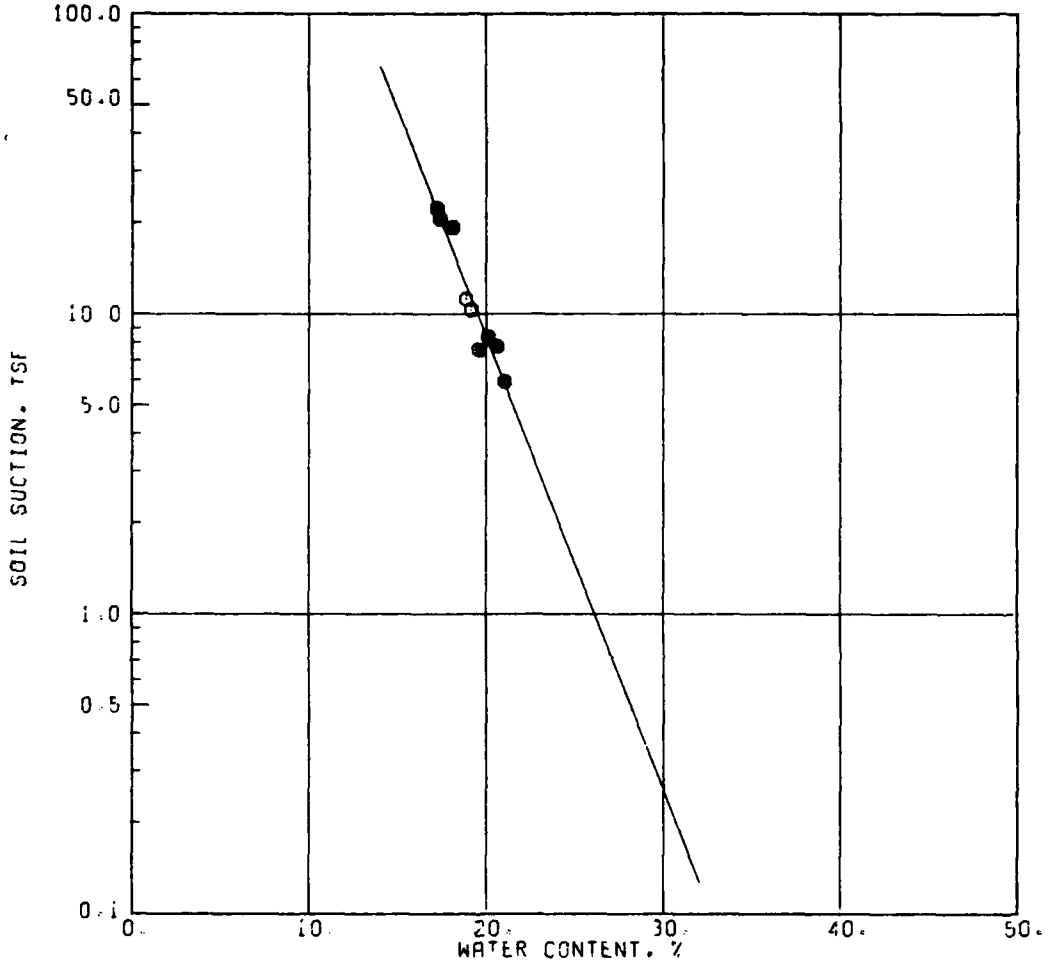
SITE: LIMON, CO #1
BOR: U-2 SAM: 4 DEP: 7.4-



SOIL SUCTION VERSUS WATER CONTENT RELATIONSHIP USING FILTER PAPER & W.E.S.-I '79 CALIBRATION CURVE

LOG SOIL SUCTION = 4.7051 -0.1679 * WATER CONTENT

SITE: LIMON, CO #1
BOR: U-2 SAM: 4 DEP: 7.4-



SOIL SUCTION VERSUS WATER CONTENT RELATIONSHIP USING FILTER PAPER & W.E.S.-II '79 CALIBRATION CURVE

LOG SOIL SUCTION = 3.9475 -0.1513 * WATER CONTENT

SITE: LIMON, CO #1
BOR: U-2 SAM: 4 DEP: 7.4-

- TABLE 1 - SOIL SUCTION AND WATER CONTENT DATA USING THERMOCOUPLE PSYCHROMETER

SITE: LIMON, CO #2
BOR: U-2 SAM: 3 DEP: 5.5-7.8 FT

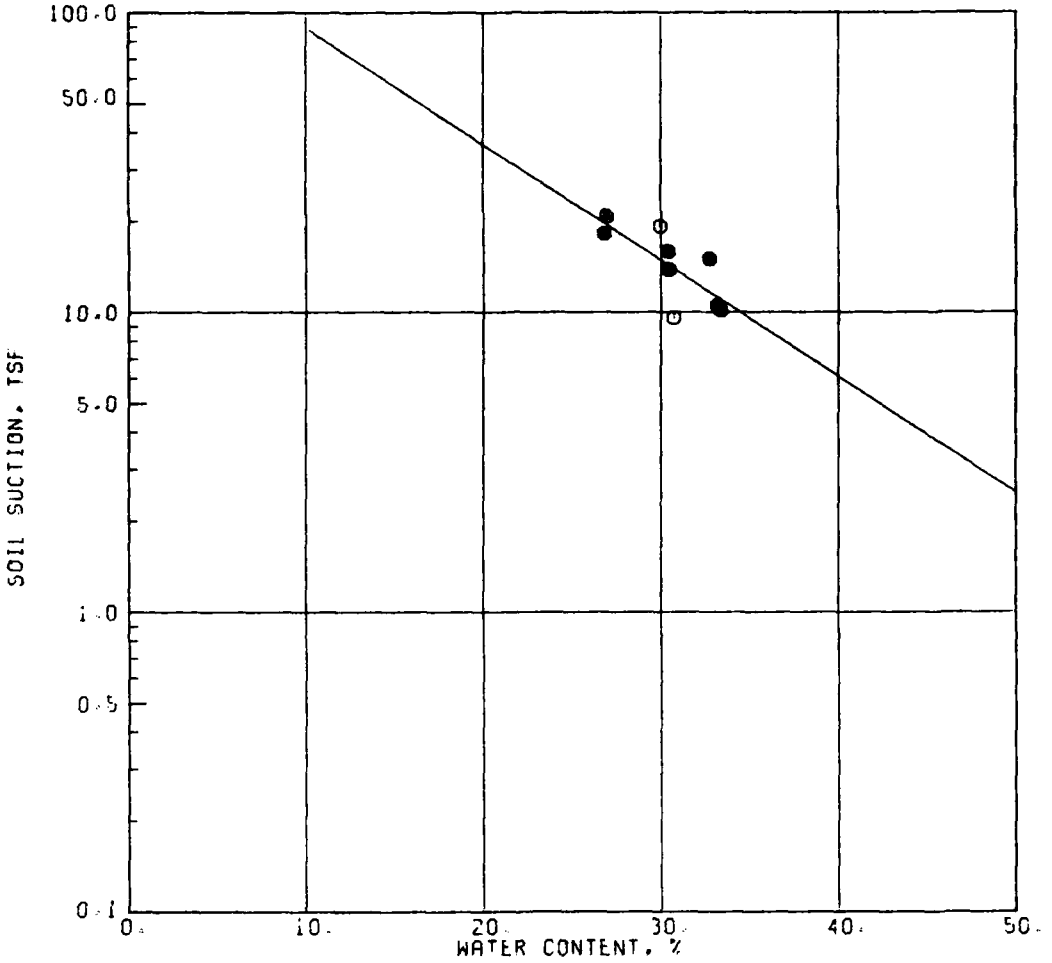
SPECIMEN NUMBER	SOIL SUCTION, TSF	WATER CONTENT %
1	19.3	29.9
2	9.6	30.7
3	13.9	30.4
4	10.5	33.2
5	15.1	32.7
6	10.1	33.3
7	16.0	30.4
8	20.9	26.9
9	18.3	26.8

LOG SOIL SUCTION = 2.3377 -0.0388 * WC

- TABLE 2 - SOIL SUCTION AND WATER CONTENT DATA USING FILTER PAPER AND CALIBRATION CURVES

SITE: LIMON, CO #2
BOR: U-2 SAM: 3 DEP: 5.5-7.8 FT

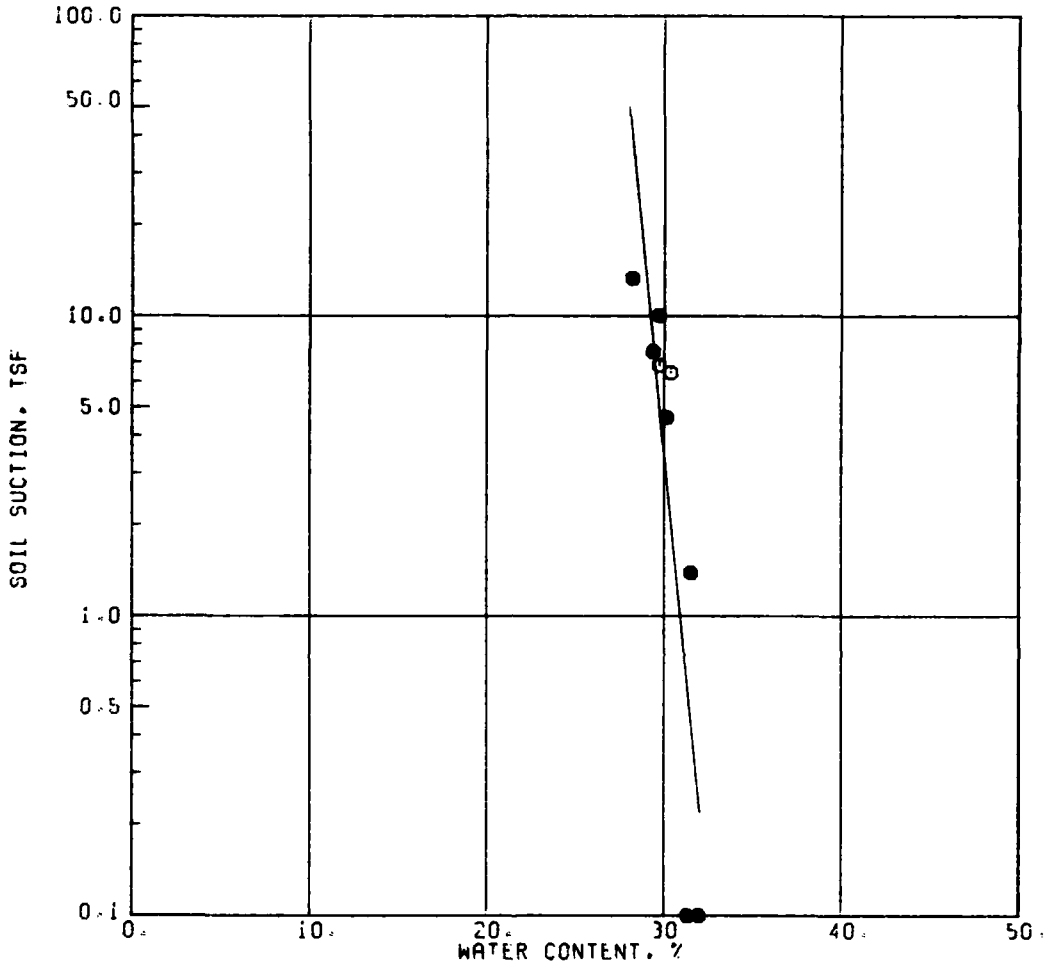
SPECIMEN NUMBER	MOISTURE CONTENT FILTER PAPER %	- - - SOIL SUCTION, TSF - - - McQUEEN/ MILLER 1968	MILLER 1978	W.E.S. I 1979	W.E.S. II 1979	SOIL WATER CONTENT %
1	33.49	6.8	6.1	2.4	1.1	29.73
2	33.82	6.5	5.8	2.3	1.1	30.38
3	35.89	4.6	4.4	1.5	0.7	30.13
4	43.06	1.4	1.7	0.3	0.2	31.49
5	59.33	0.1	0.2	0.1	0.1	31.95
6	118.81	0.1	0.1	0.1	0.1	31.28
7	32.86	7.6	6.6	2.8	1.3	29.34
8	31.19	10.0	8.3	4.0	1.8	29.67
9	29.47	13.4	10.5	5.7	2.4	28.17



SOIL SUCTION VERSUS WATER CONTENT RELATIONSHIP USING THERMOCOUPLE PSYCHROMETERS

LOG SOIL SUCTION = 2.3377 -0.0388 * WATER CONTENT

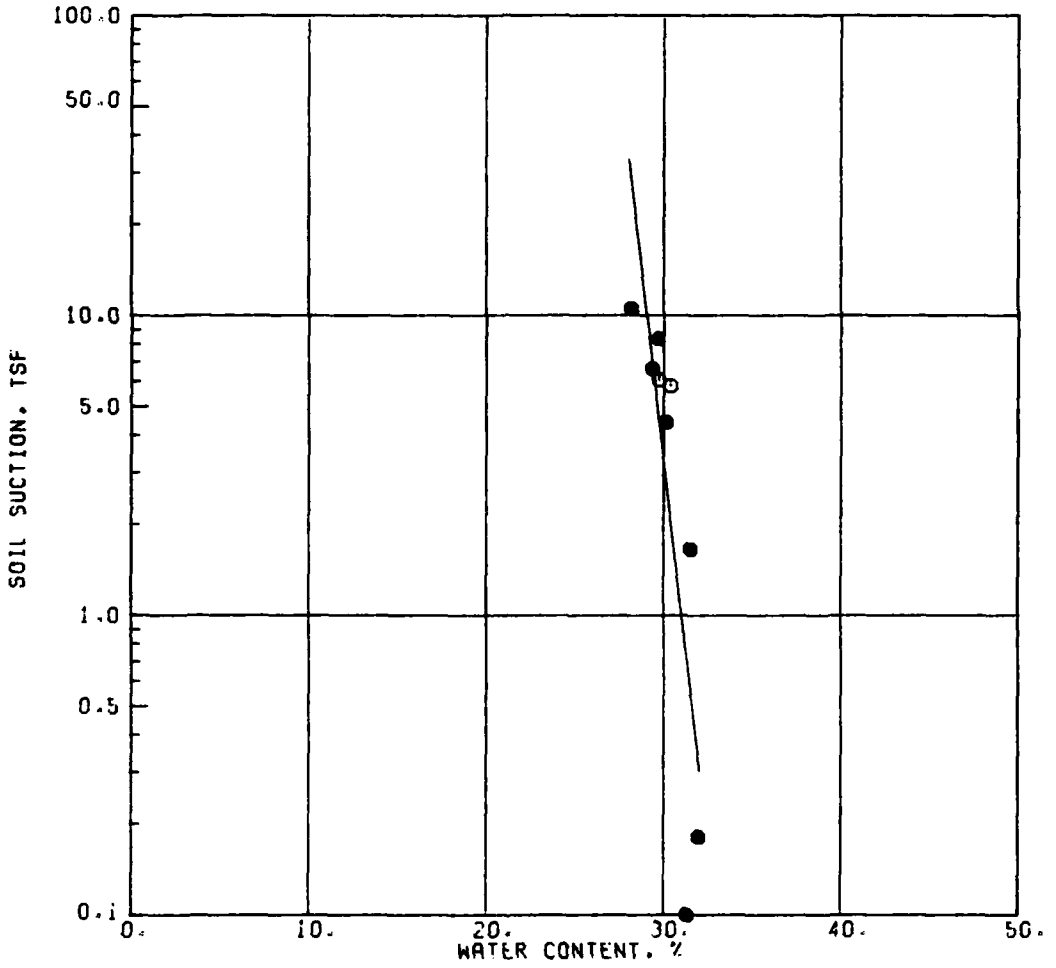
SITE: LIMON, CO #2
BOR: U-2 SAM: 3 DEP: 5.5-



SOIL SUCTION VERSUS WATER CONTENT RELATIONSHIP USING FILTER PAPER & MCQUEEN/MILLER '68 CALIBRATION CURVE

LOG SOIL SUCTION = 18.2052 -0.5894 * WATER CONTENT

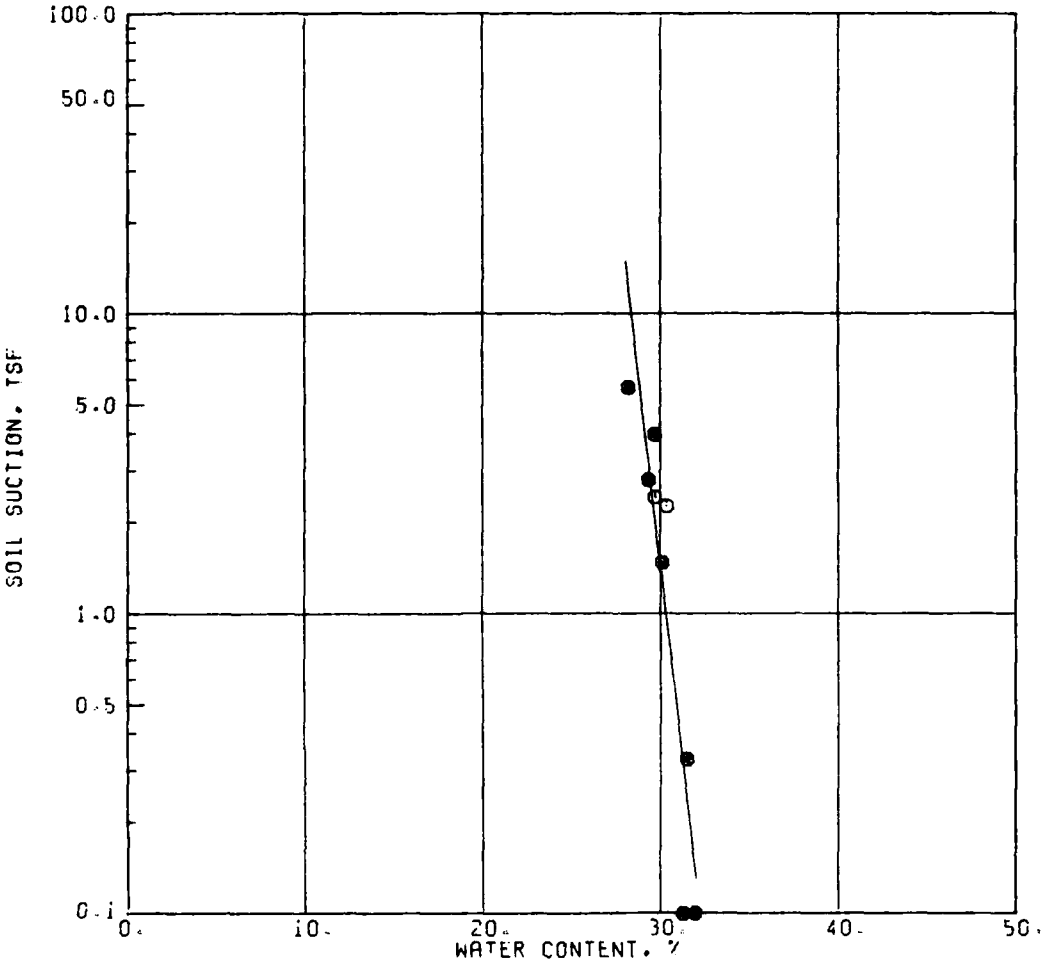
SITE: LIMON, CO #2
BOR: U-2 SAM: 3 DEP: 5.5-



SOIL SUCTION VERSUS WATER CONTENT RELATIONSHIP USING FILTER PAPER & MILLER '78 CALIBRATION CURVE

LOG SOIL SUCTION = 15.8503 -0.5116 * WATER CONTENT

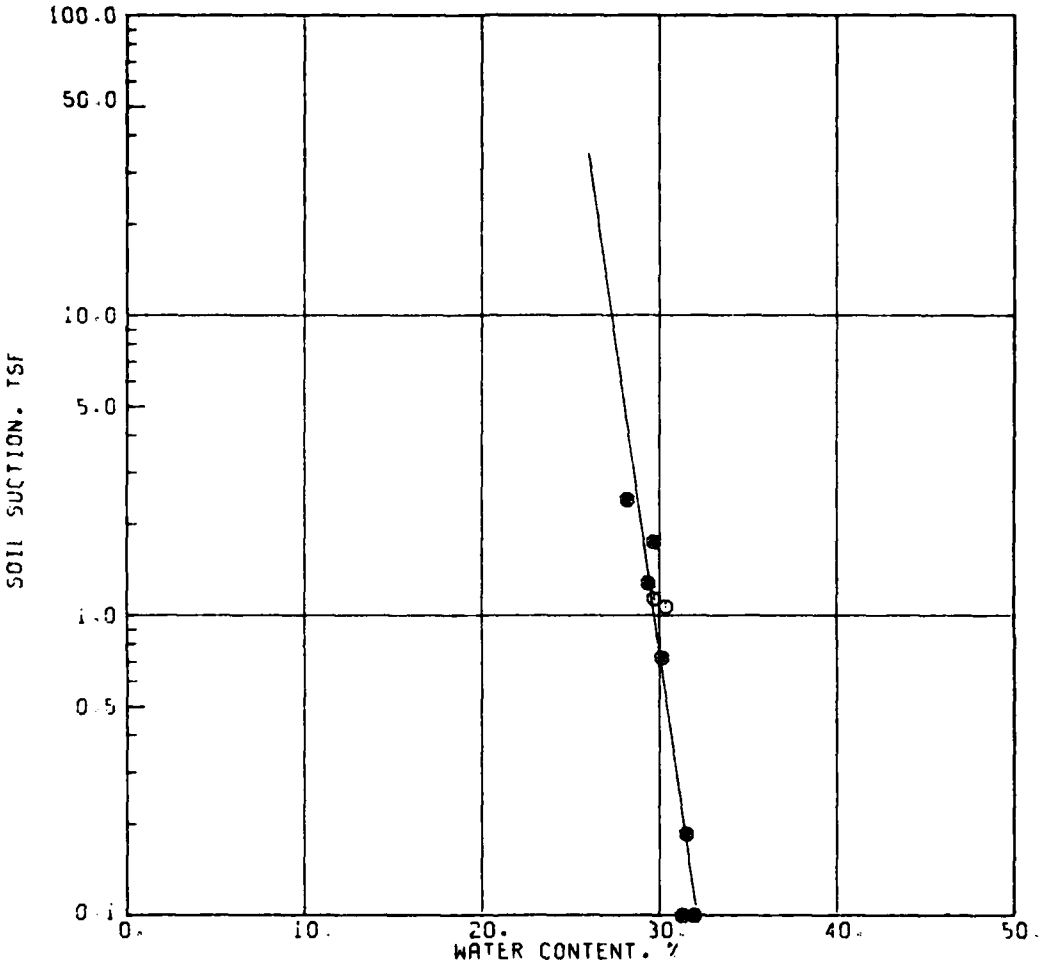
SITE: LIMON, CO #2
BOR: U-2 SAM: 3 DEP: 5.5-



SOIL SUCTION VERSUS WATER CONTENT RELATIONSHIP USING FILTER PAPER & W.E.S.-I '79 CALIBRATION CURVE

LOG SOIL SUCTION = 15.6335 -0.5162 * WATER CONTENT

SITE: LIMON, CO #2
BOR: U-2 SAM: 3 DEP: 5.5-



SOIL SUCTION VERSUS WATER CONTENT RELATIONSHIP USING FILTER PAPER & W.E.S.-II '79 CALIBRATION CURVE

LOG SOIL SUCTION = 12.4077 -0.4178 * WATER CONTENT

SITE: LIMON, CO #2
BOR: U-2 SAM: 3 DEP: 5.5-

- TABLE 1 - SOIL SUCTION AND WATER CONTENT DATA USING THERMOCOUPLE PSYCHROMETER

SITE: DENVER, CO
BOR: U-3 SAM: 4 DEP: 5.7-7.8 FT

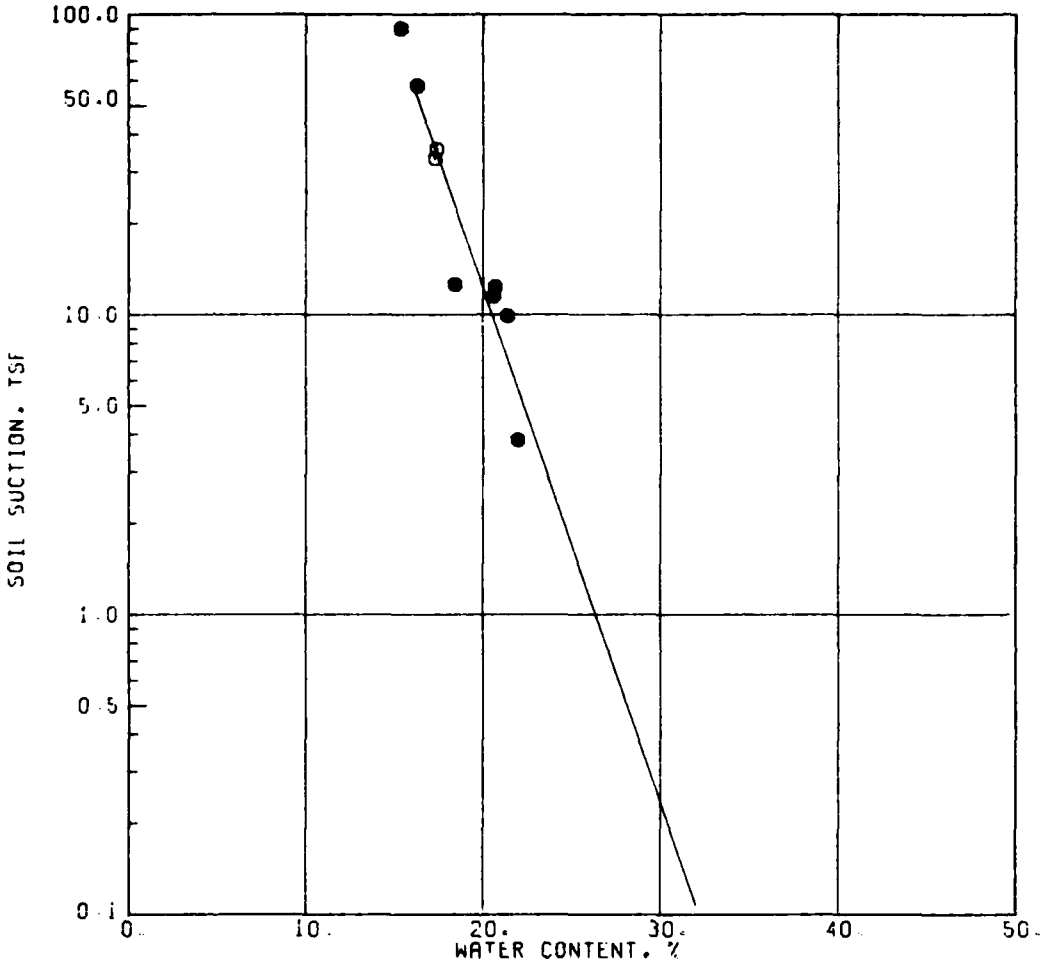
SPECIMEN NUMBER	SOIL SUCTION, TSF	WATER CONTENT %
1	33.1	17.3
2	35.6	17.4
3	12.6	18.4
4	11.5	20.6
5	12.4	20.7
6	3.8	22.0
7	9.9	21.4
8	57.9	16.3
9	89.6	15.3

LOG SOIL SUCTION = 4.5135 -0.1713 * WC

- TABLE 2 - SOIL SUCTION AND WATER CONTENT DATA USING FILTER PAPER AND CALIBRATION CURVES

SITE: DENVER, CO
BOR: U-3 SAM: 4 DEP: 5.7-7.8 FT

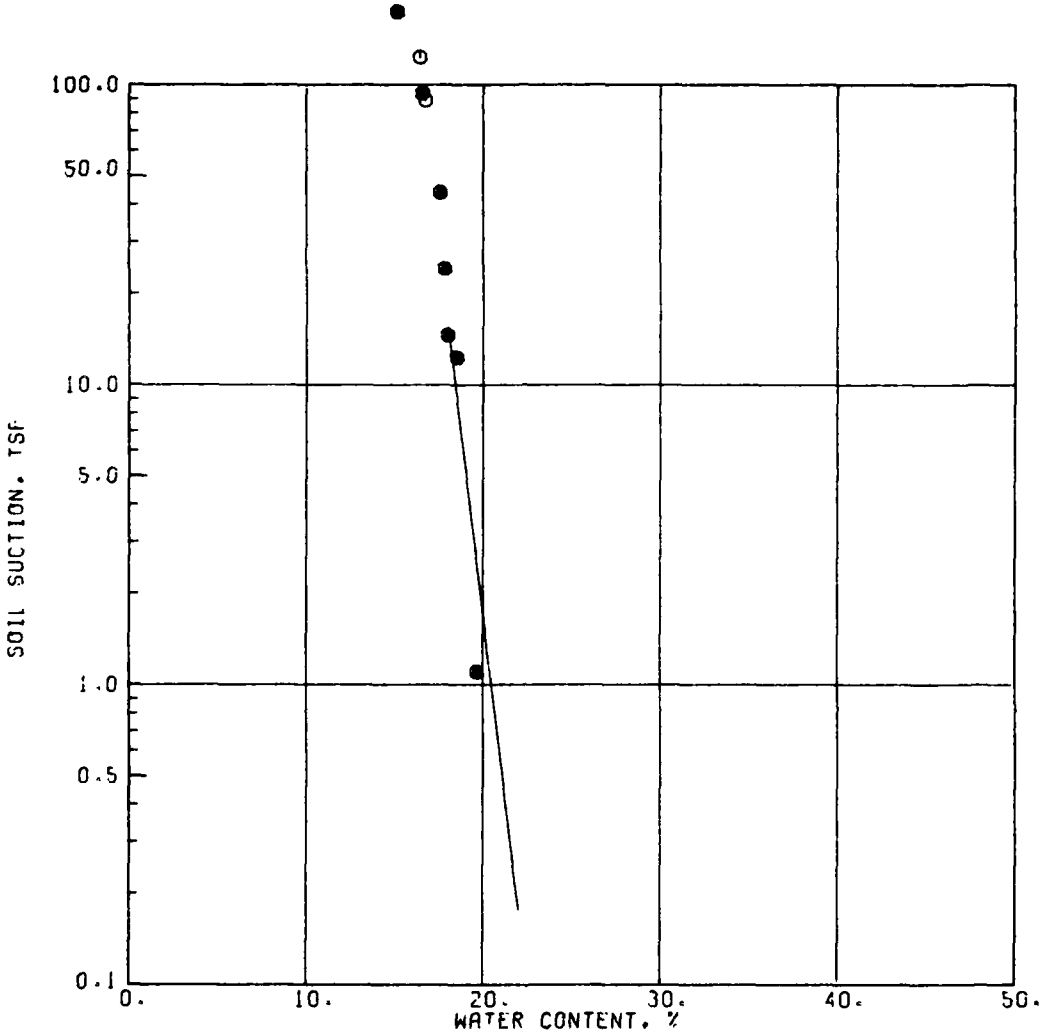
SPECIMEN NUMBER	MOISTURE CONTENT FILTER PAPER %	- - - SOIL SUCTION, TSF - - - McQUEEN/ MILLER 1968	MILLER 1978	W.E.S. I 1979	W.E.S. II 1979	SOIL WATER CONTENT %
1	16.11	123.4	64.5	93.0	30.3	16.41
2	18.10	88.7	49.3	61.4	20.9	16.74
3	22.33	43.8	27.7	25.3	9.4	17.57
4	28.91	14.7	11.3	6.4	2.7	17.98
5	44.44	1.1	1.4	0.2	0.1	19.64
6	25.84	24.5	17.2	12.1	4.8	17.80
7	29.95	12.5	9.8	5.1	2.2	18.50
8	17.77	93.7	51.5	65.8	22.2	16.52
9	14.01	175.2	85.8	144.6	45.1	15.10



SOIL SUCTION VERSUS WATER CONTENT RELATIONSHIP USING THERMOCOUPLE PSYCHROMETERS

LOG SOIL SUCTION = 4.5135 -0.1713 * WATER CONTENT

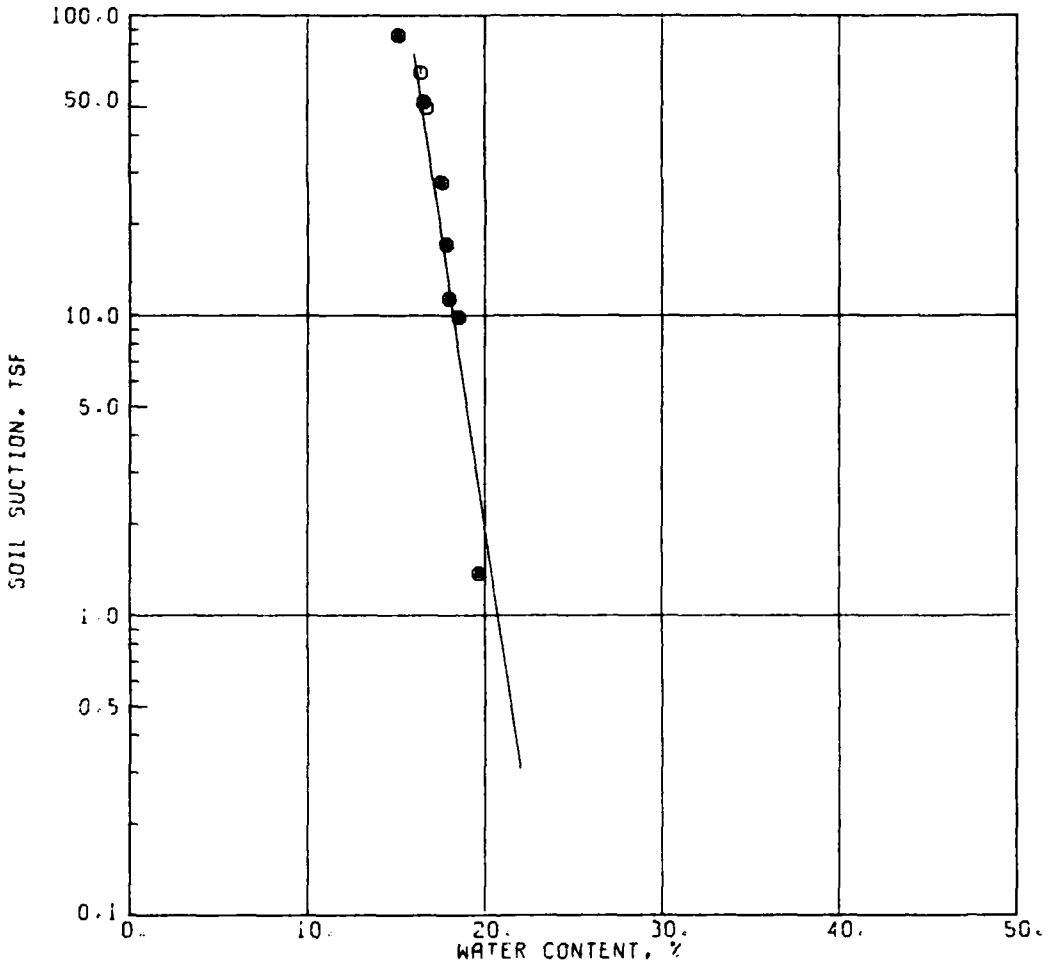
SITE: DENVER, CO
BOR: U-3 SAM: 4 DEP: 5.7-



SOIL SUCTION VERSUS WATER CONTENT RELATIONSHIP USING FILTER PAPER & MCQUEEN/MILLER '68 CALIBRATION CURVE

LOG SOIL SUCTION = 9.9800 -0.4879 * WATER CONTENT

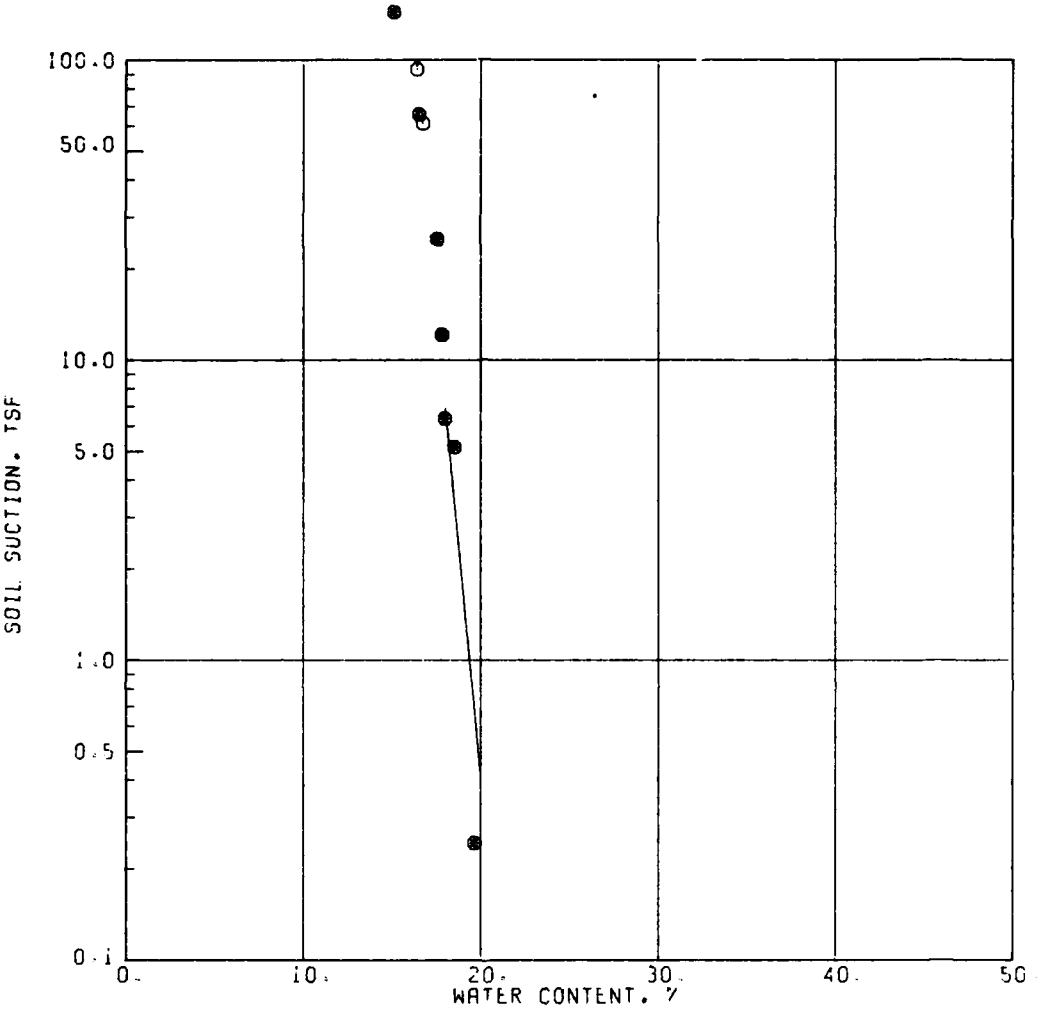
SITE: DENVER, CO
BOR: U-3 SAM: 4 DEP: 5.7-



SOIL SUCTION VERSUS WATER CONTENT RELATIONSHIP USING FILTER PAPER & MILLER '78 CALIBRATION CURVE

LOG SOIL SUCTION = 8.2470 -0.3981 * WATER CONTENT

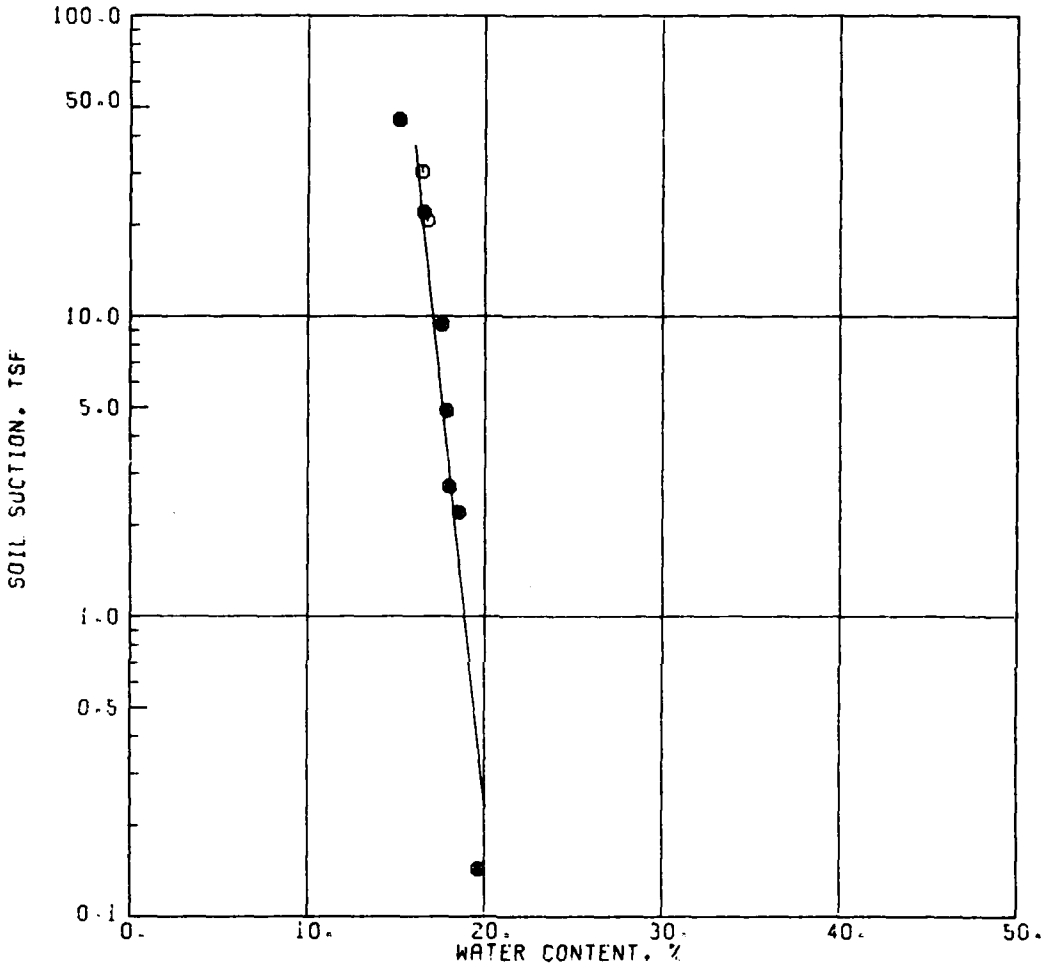
SITE: DENVER, CO
BOR: U-3 SAM: 4 DEP: 5.7-



SOIL SUCTION VERSUS WATER CONTENT RELATIONSHIP USING
FILTER PAPER & W.E.S.-I '79 CALIBRATION CURVE

LOG SOIL SUCTION = 11.8976 -0.6141 * WATER CONTENT

SITE: DENVER, CO
BOR: U-3 SAM: 4 DEP: 5.7-



SOIL SUCTION VERSUS WATER CONTENT RELATIONSHIP USING FILTER PAPER & W.E.S.-II '79 CALIBRATION CURVE

LOG SOIL SUCTION = 10.4287 -0.5533 * WATER CONTENT

SITE: DENVER, CO
BOR: U-3 SAM: 4 DEP: 5.7-

- TABLE 1 - SOIL SUCTION AND WATER CONTENT DATA USING THERMOCOUPLE PSYCHROMETER

SITE: NEWCASTLE, WY #1
BOR: U-2 SAM: 4 DEP: 7.3-9.8 FT

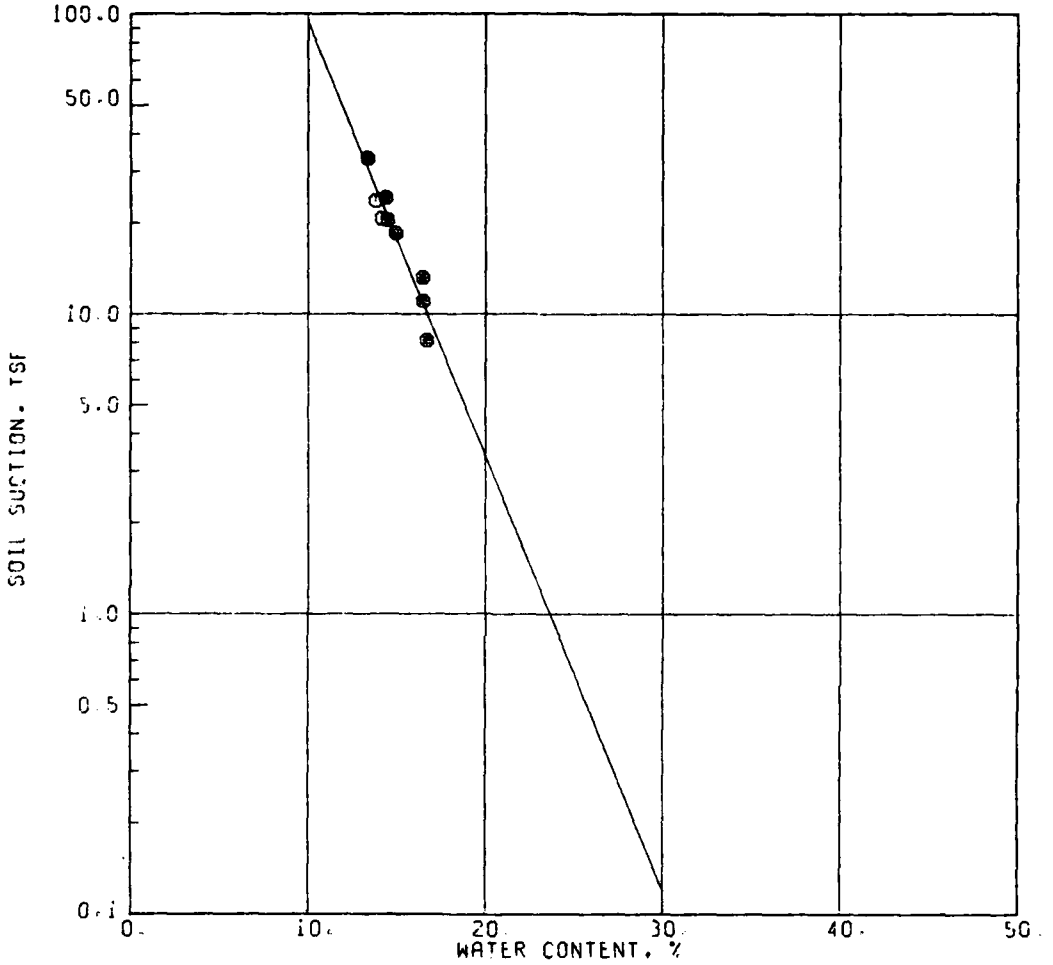
SPECIMEN NUMBER	SOIL SUCTION, TSF	WATER CONTENT %
1	23.8	13.8
2	20.8	14.2
3	18.5	15.0
4	11.0	16.5
5	13.2	16.5
6	8.2	16.7
7	20.5	14.5
8	24.4	14.4
9	32.9	13.3

LOG SOIL SUCTION = 3.4158 -0.1446 * WC

- TABLE 2 - SOIL SUCTION AND WATER CONTENT DATA USING FILTER PAPER AND CALIBRATION CURVES

SITE: NEWCASTLE, WY #1
BOR: U-2 SAM: 4 DEP: 7.3-9.8 FT

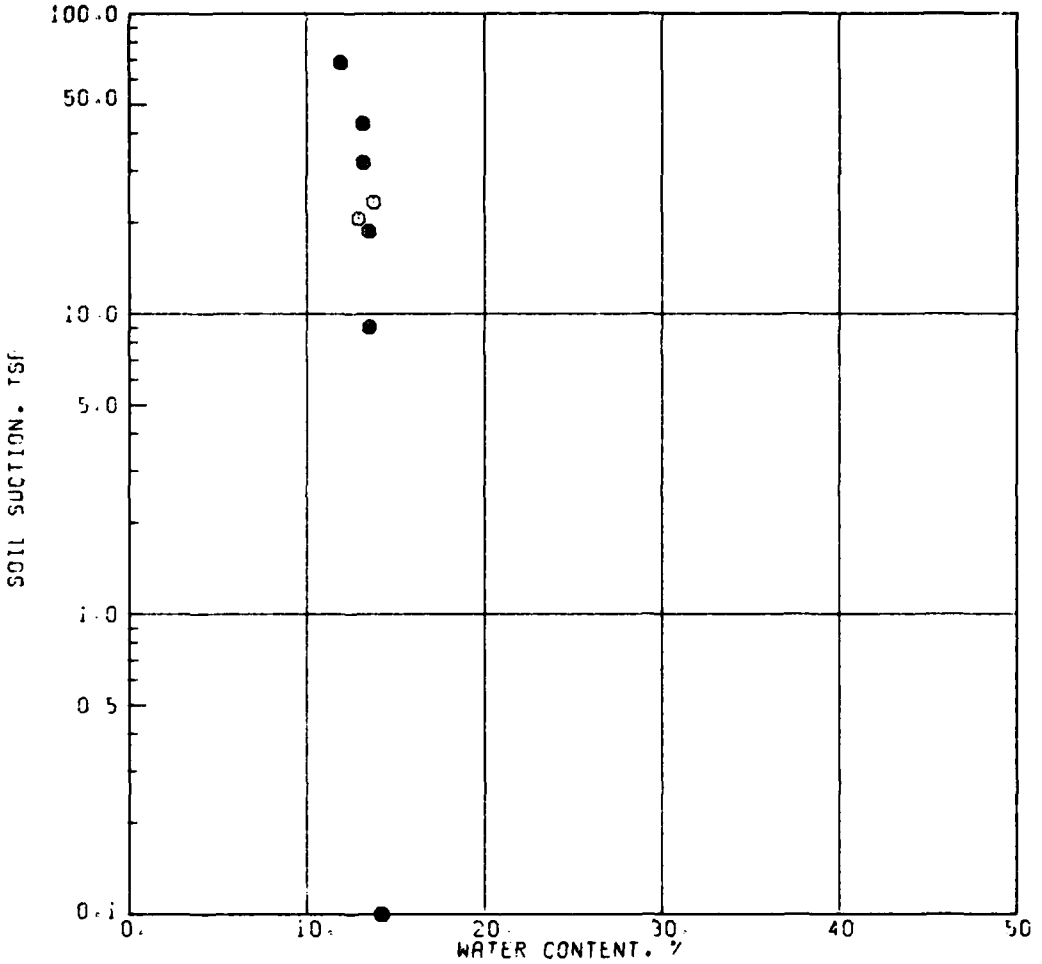
SPECIMEN NUMBER	MOISTURE CONTENT FILTER PAPER %	- - - SOIL SUCTION, TSF - - - McQUEEN/ MILLER 1968	MILLER 1978	W.E.S. I 1979	W.E.S. II 1979	SOIL WATER CONTENT %
1	26.82	20.8	15.1	9.9	4.0	12.93
2	26.07	23.5	16.7	11.6	4.6	13.81
3	27.40	18.8	13.9	8.7	3.6	13.49
4	31.82	9.0	7.6	3.5	1.6	13.51
5	105.48	0.1	0.1	0.1	0.1	14.16
6	132.85	0.1	0.1	0.1	0.1	14.23
7	24.22	32.0	21.5	17.0	6.6	13.14
8	22.43	43.1	27.3	24.8	9.2	13.12
9	19.63	68.8	40.0	44.6	15.6	11.90



SOIL SUCTION VERSUS WATER CONTENT RELATIONSHIP USING THERMOCOUPLE PSYCHROMETERS

LOG SOIL SUCTION = 3.4158 -0.1446 * WATER CONTENT

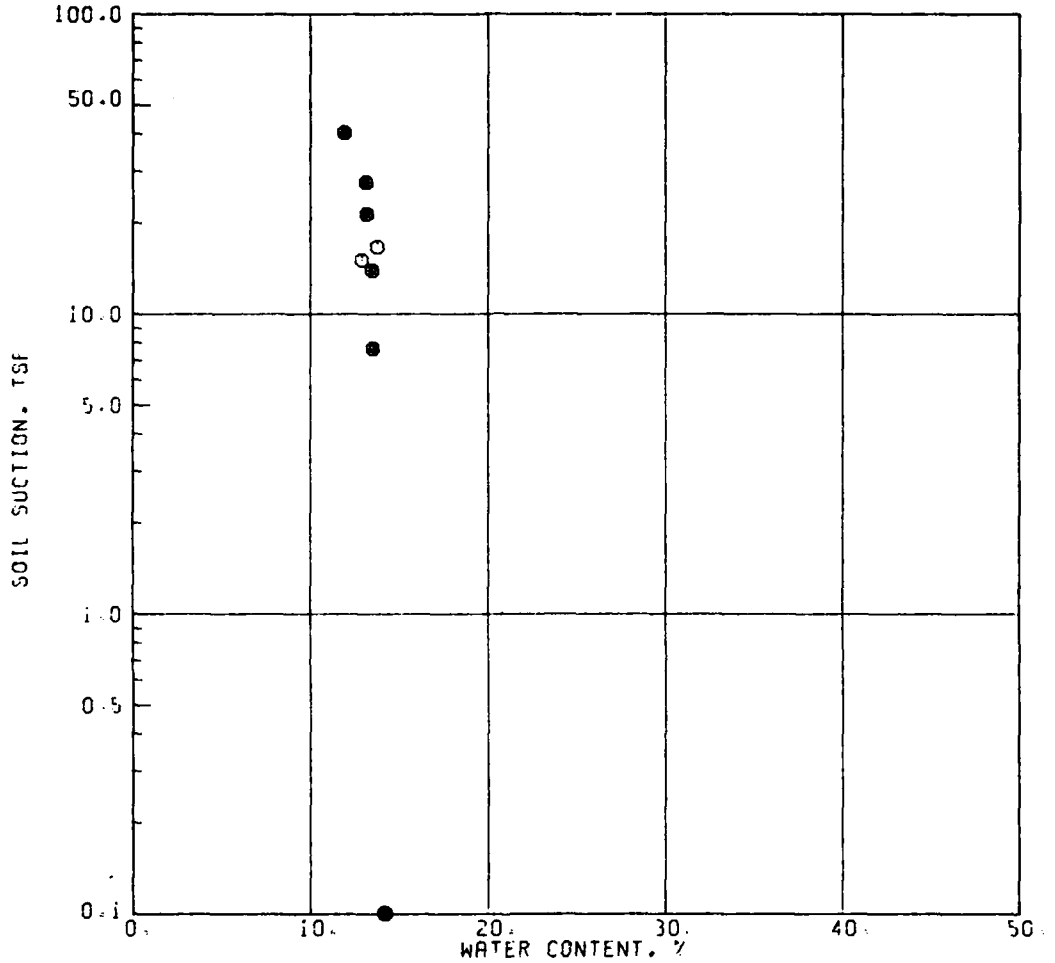
SITE: NEWCASTLE, WY #1
BOR: U-2 SAM: 4 DEP: 7.3-



SOIL SUCTION VERSUS WATER CONTENT RELATIONSHIP USING FILTER PAPER & MCQUEEN/MILLER '68 CALIBRATION CURVE

LOG SOIL SUCTION = 16.5574 -1.1733 * WATER CONTENT

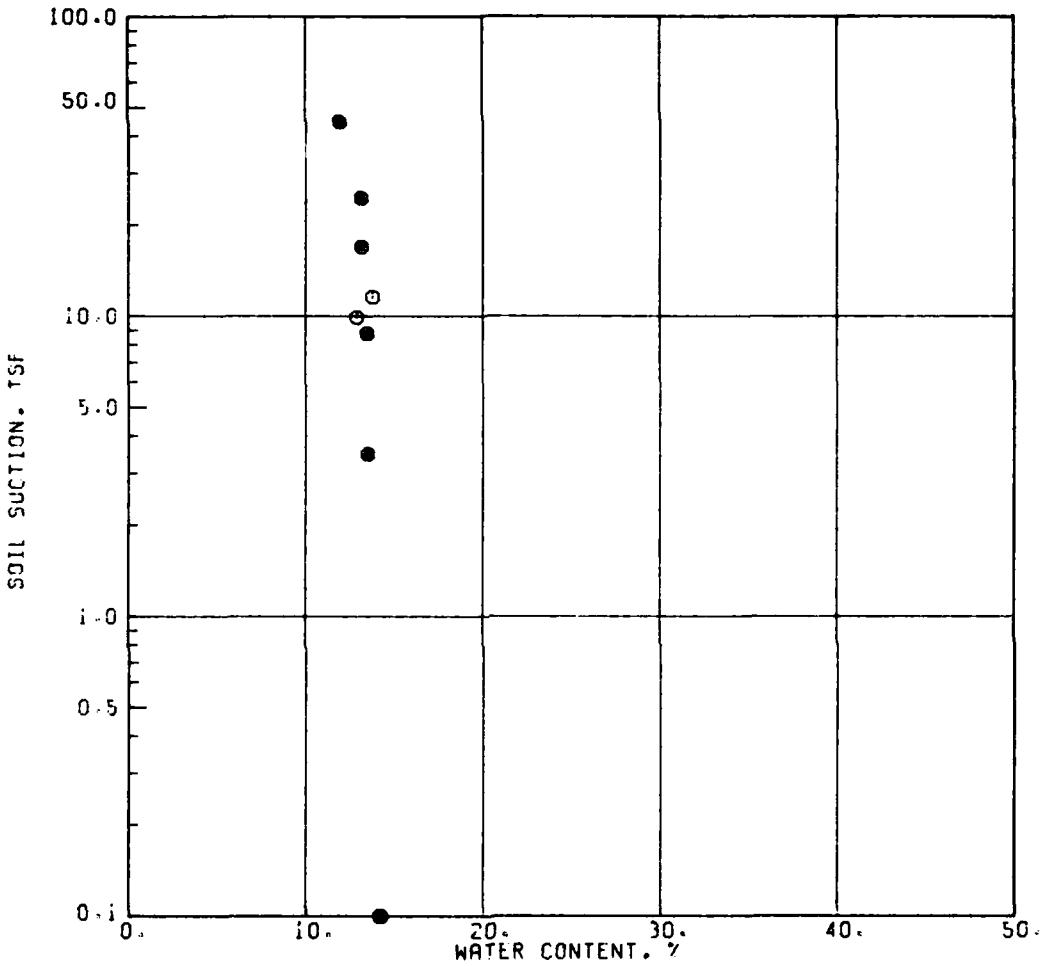
SITE: NEWCASTLE, WY #1
BOR: U-2 SAM: 4 DEP: 7.3-



SOIL SUCTION VERSUS WATER CONTENT RELATIONSHIP USING FILTER PAPER & MILLER '78 CALIBRATION CURVE

LOG SOIL SUCTION = 15.1166 -1.0746 * WATER CONTENT

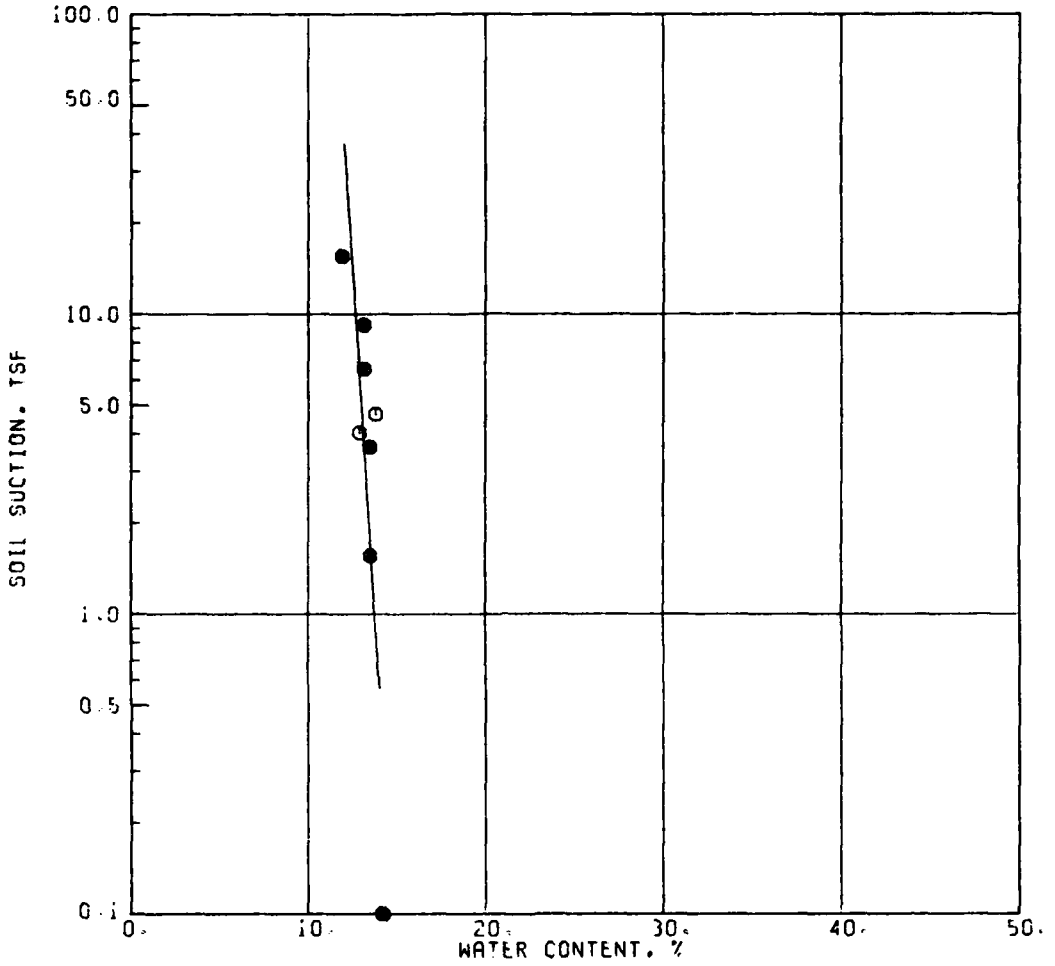
SITE: NEWCASTLE, WY #1
BOR: U-2 SAM: 4 DEP: 7.3-



SOIL SUCTION VERSUS WATER CONTENT RELATIONSHIP USING FILTER PAPER & W.E.S.-I '79 CALIBRATION CURVE

LOG SOIL SUCTION = 15.3451 -1.0999 * WATER CONTENT

SITE: NEWCASTLE, WY #1
BOR: U-2 SAM: 4 DEP: 7.3-



SOIL SUCTION VERSUS WATER CONTENT RELATIONSHIP USING FILTER PAPER & W.E.S.-II '79 CALIBRATION CURVE

LOG SOIL SUCTION = 12.5222 -0.9121 * WATER CONTENT

SITE: NEWCASTLE, WY #1
BOR: U-2 SAM: 4 DEP: 7.3-

- TABLE 1 - SOIL SUCTION AND WATER CONTENT DATA
USING THERMOCOUPLE PSYCHROMETER

SITE: NEWCASTLE WY #2
BOR: U-2 SAM: 4 DEP: 6.1-8.3 FT

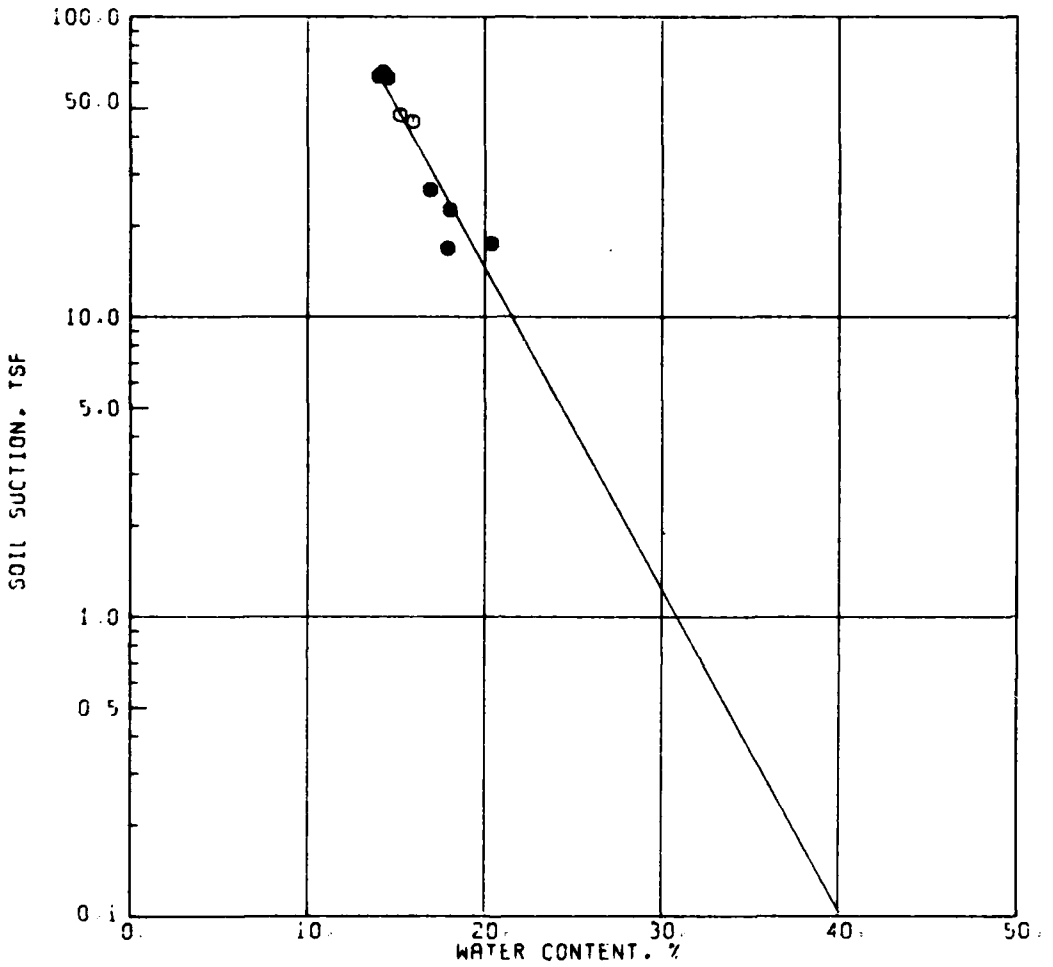
SPECIMEN NUMBER	SOIL SUCTION, TSF	WATER CONTENT %
1	44.7	16.0
2	47.0	15.3
3	26.5	16.9
4	22.7	18.0
5	16.9	17.9
6	17.5	20.4
7	62.6	14.5
8	65.2	14.3
9	63.2	14.0

LOG SOIL SUCTION = 3.3093 -0.1073 * WC

- TABLE 2 - SOIL SUCTION AND WATER CONTENT DATA
USING FILTER PAPER AND CALIBRATION CURVES

SITE: NEWCASTLE WY #2
BOR: U-2 SAM: 4 DEP: 6.1-8.3 FT

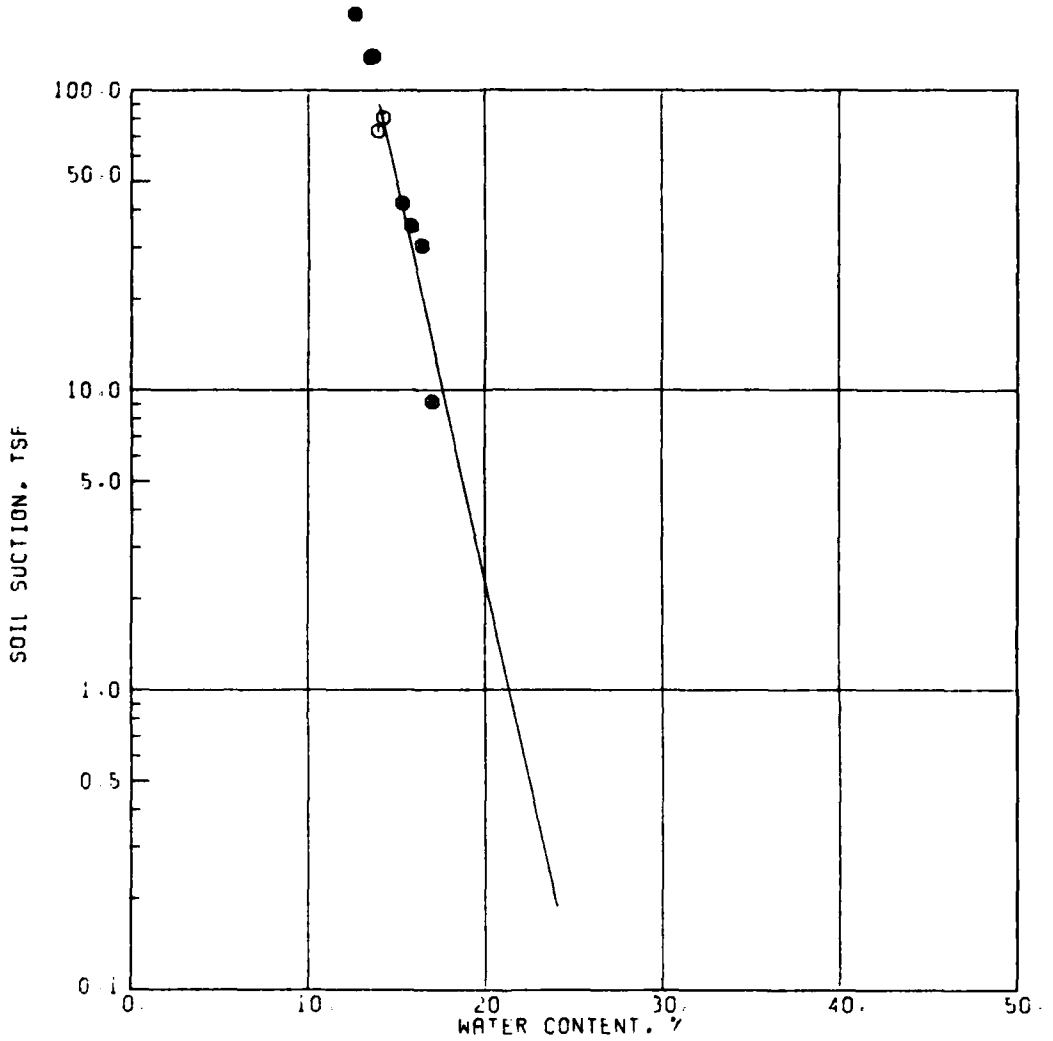
SPECIMEN NUMBER	MOISTURE CONTENT FILTER PAPER %	- - - SOIL SUCTION, TSF - - - McQUEEN/ MILLER 1968	MILLER 1978	W.E.S. I 1979	W.E.S. II 1979	SOIL WATER CONTENT %
1	19.27	73.0	42.0	48.1	16.7	13.99
2	18.64	81.1	45.8	54.8	18.8	14.28
3	22.58	42.1	26.8	24.0	8.9	15.33
4	23.62	35.4	23.3	19.3	7.4	15.80
5	24.54	30.4	20.5	15.9	6.2	16.38
6	31.75	9.1	7.7	3.5	1.6	17.00
7	15.87	128.6	66.7	98.0	31.8	13.52
8	15.81	129.7	67.2	99.1	32.1	13.68
9	13.86	179.6	87.6	149.1	46.4	12.69



SOIL SUCTION VERSUS WATER CONTENT RELATIONSHIP USING THERMOCOUPLE PSYCHROMETERS

LOG SOIL SUCTION = 3.3093 -0.1073 * WATER CONTENT

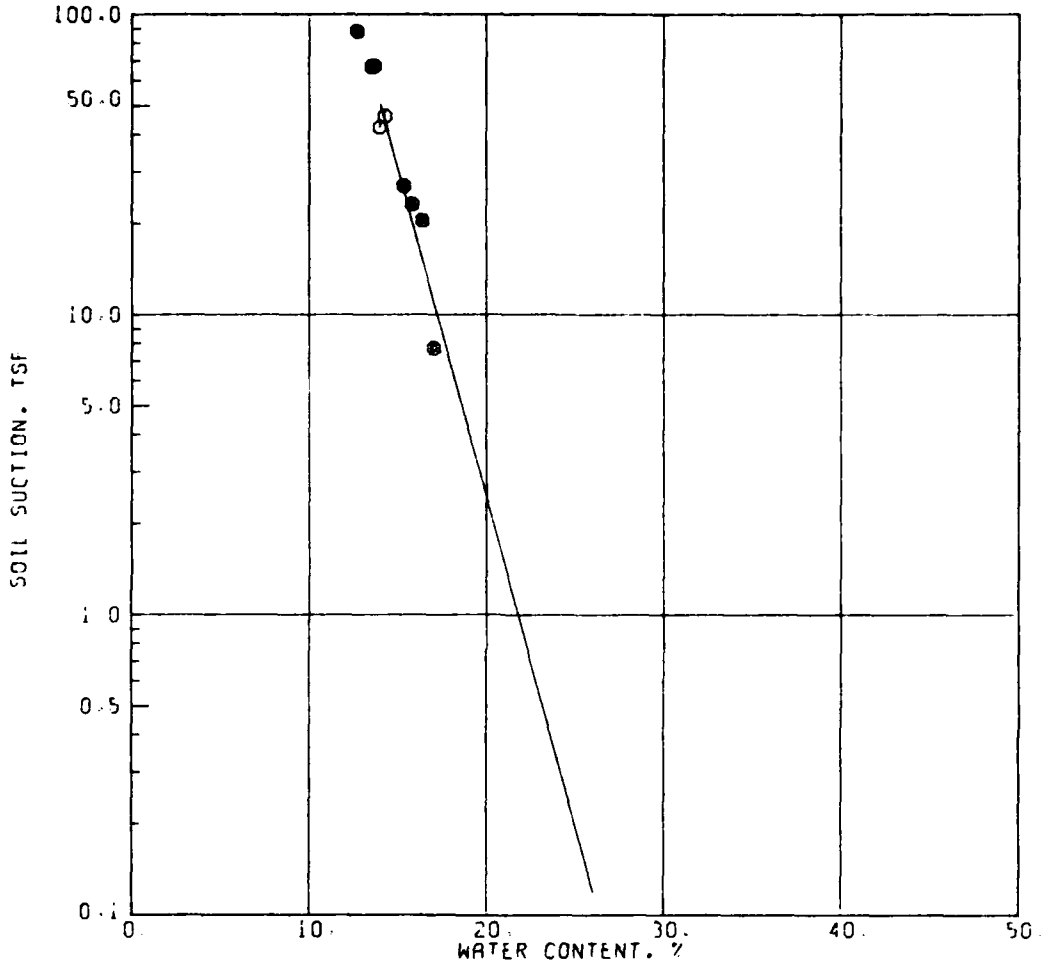
SITE: NEWCASTLE WY #2
BOR: U-2 SAM: 4 DEP: 6.1-



SOIL SUCTION VERSUS WATER CONTENT RELATIONSHIP USING FILTER PAPER & MCQUEEN/MILLER '68 CALIBRATION CURVE

LOG SOIL SUCTION = 5.7157 -0.2682 * WATER CONTENT

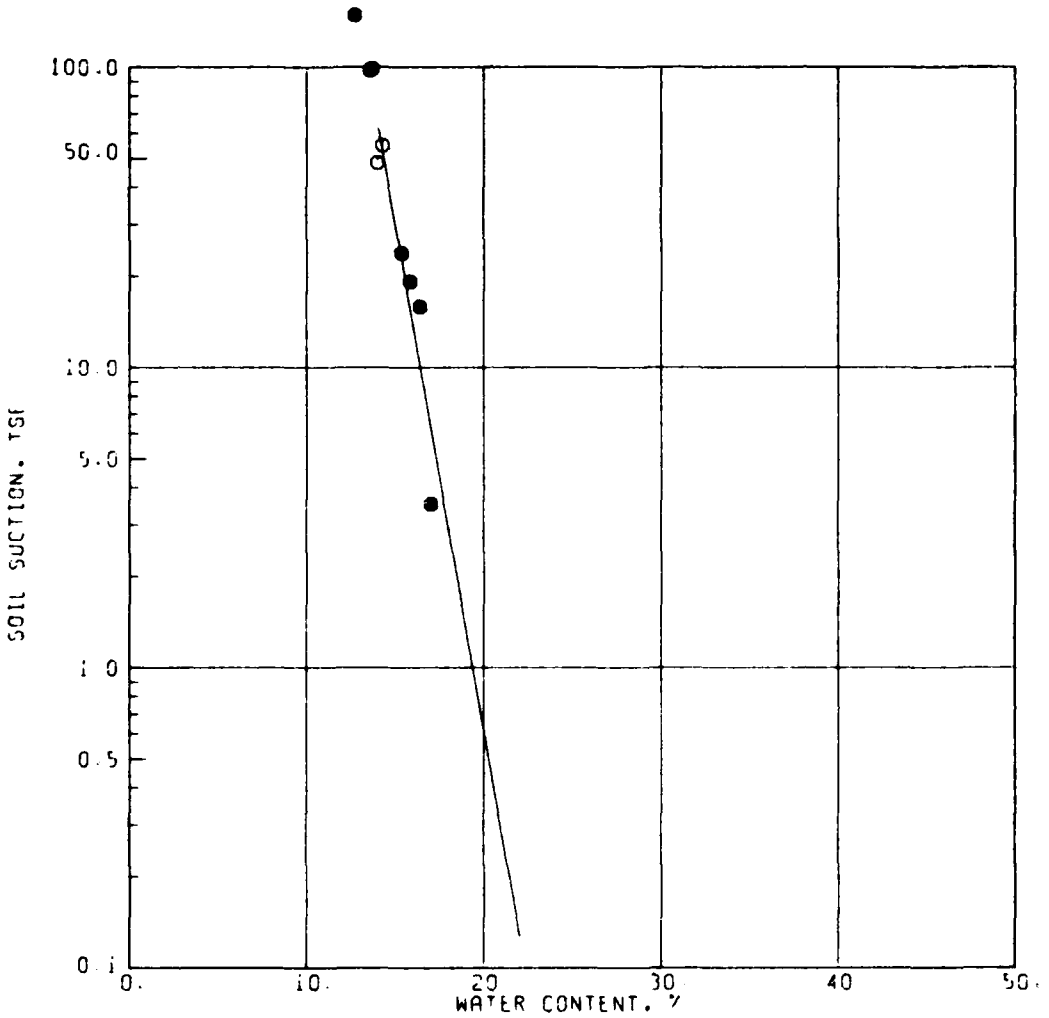
SITE: NEWCASTLE WY #2
BOR: U-2 SAM: 4 DEP: 6.1-



SOIL SUCTION VERSUS WATER CONTENT RELATIONSHIP USING FILTER PAPER & MILLER '78 CALIBRATION CURVE

LOG SOIL SUCTION = 4.7671 -0.2188 * WATER CONTENT

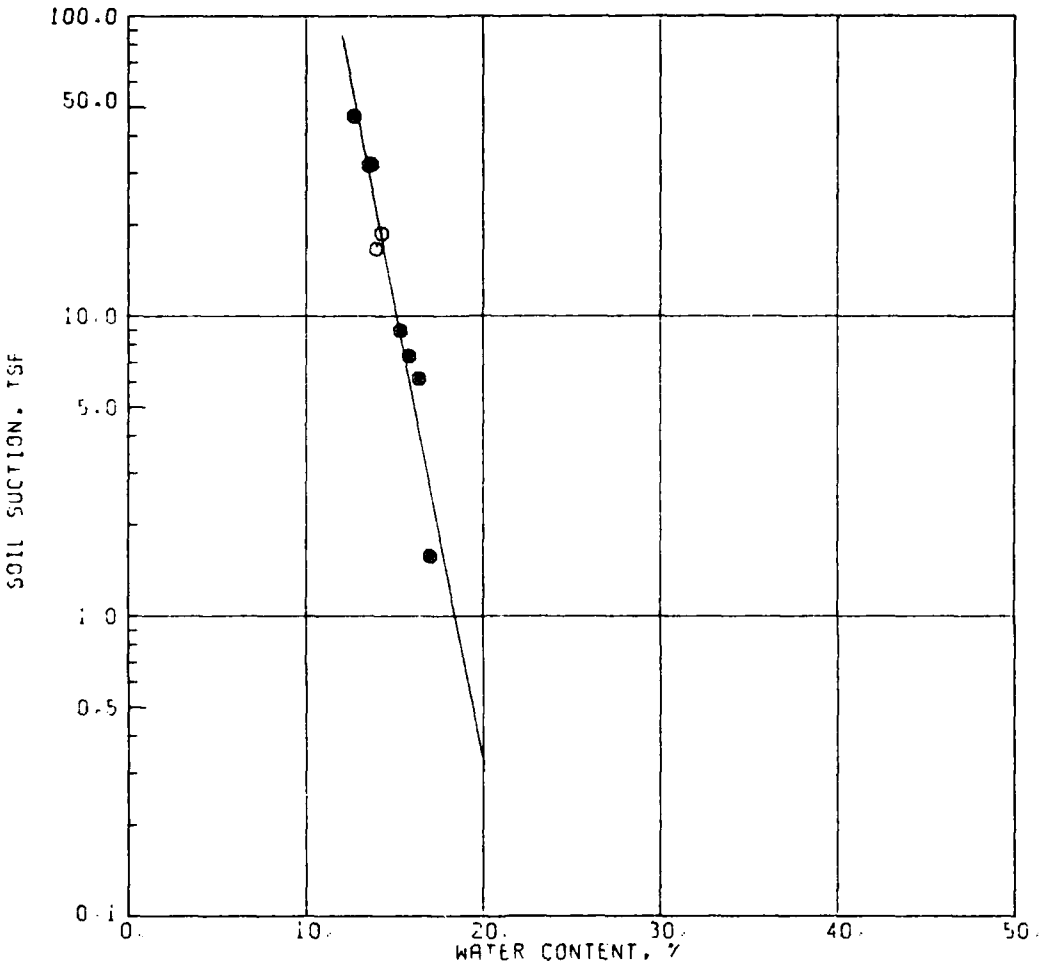
SITE: NEWCASTLE WY #2
BOR: U-2 SAM: 4 DEP: 6.1-



SOIL SUCTION VERSUS WATER CONTENT RELATIONSHIP USING FILTER PAPER & W.E.S.-I '79 CALIBRATION CURVE

LOG SOIL SUCTION = 6.5303 -0.3375 * WATER CONTENT

SITE: NEWCASTLE WY #2
BOR: U-2 SAM: 4 DEP: 6.1-



SOIL SUCTION VERSUS WATER CONTENT RELATIONSHIP USING FILTER PAPER & W.E.S.-II '79 CALIBRATION CURVE

LOG SOIL SUCTION = 5.5922 -0.3042 * WATER CONTENT

SITE: NEWCASTLE WY #2
BOR: U-2 SAM: 4 DEP: 6.1-

- TABLE 1 - SOIL SUCTION AND WATER CONTENT DATA USING THERMOCOUPLE PSYCHROMETER

SITE: BILLINGS, MT
BOR: U-2 SAM: 4 DEP: 6.7-9.2 FT

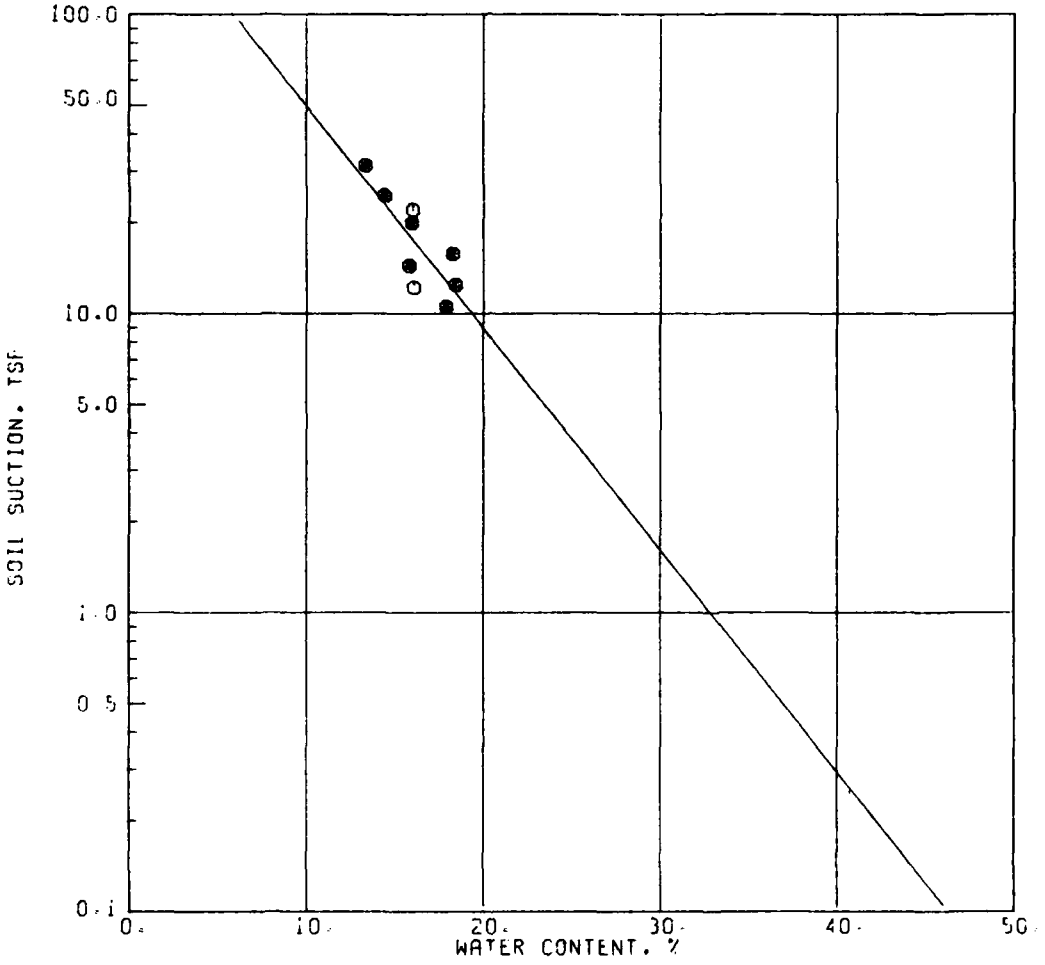
SPECIMEN NUMBER	SOIL SUCTION, TSF	WATER CONTENT %
1	22.2	16.0
2	12.2	16.1
3	14.4	15.8
4	12.4	18.4
5	15.8	18.2
6	10.5	17.9
7	20.1	15.9
8	24.8	14.4
9	31.2	13.3

LOG SOIL SUCTION = 2.4384 -0.0743 * WC

- TABLE 2 - SOIL SUCTION AND WATER CONTENT DATA USING FILTER PAPER AND CALIBRATION CURVES

SITE: BILLINGS, MT
BOR: U-2 SAM: 4 DEP: 6.7-9.2 FT

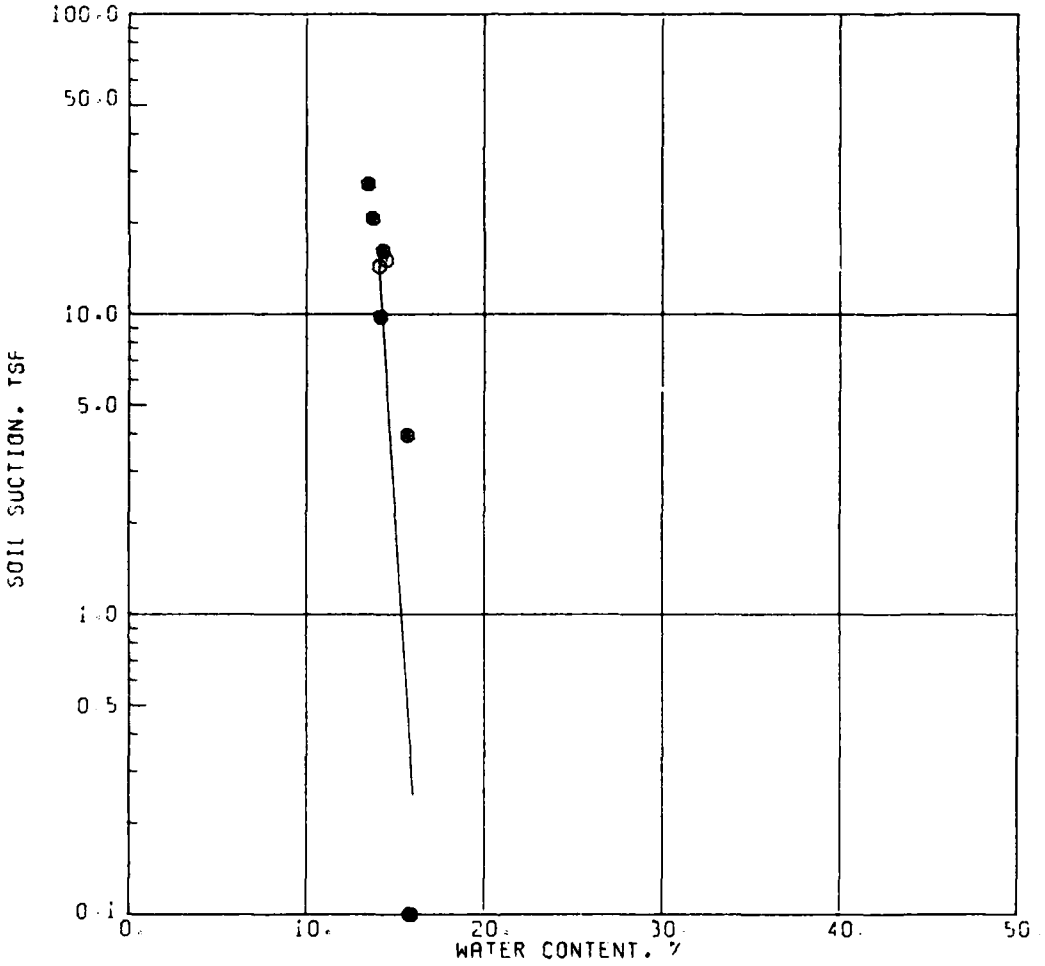
SPECIMEN NUMBER	MOISTURE CONTENT FILTER PAPER %	- - - SOIL SUCTION, TSF - - - McQUEEN/ MILLER 1968	MILLER 1978	W.E.S. I 1979	W.E.S. II 1979	SOIL WATER CONTENT %
1	28.70	15.2	11.7	6.7	2.8	14.49
2	29.00	14.4	11.2	6.2	2.7	14.10
3	31.34	9.8	8.2	3.8	1.7	14.17
4	36.79	3.9	3.9	1.2	0.6	15.48
5	93.58	0.1	0.1	0.1	0.1	15.82
6	107.80	0.1	0.1	0.1	0.1	15.90
7	28.29	16.2	12.3	7.3	3.0	14.26
8	26.79	20.9	15.1	9.9	4.0	13.72
9	25.22	27.1	18.7	13.8	5.4	13.47



SOIL SUCTION VERSUS WATER CONTENT RELATIONSHIP USING THERMOCOUPLE PSYCHROMETERS

LOG SOIL SUCTION = 2.4384 -0.0743 * WATER CONTENT

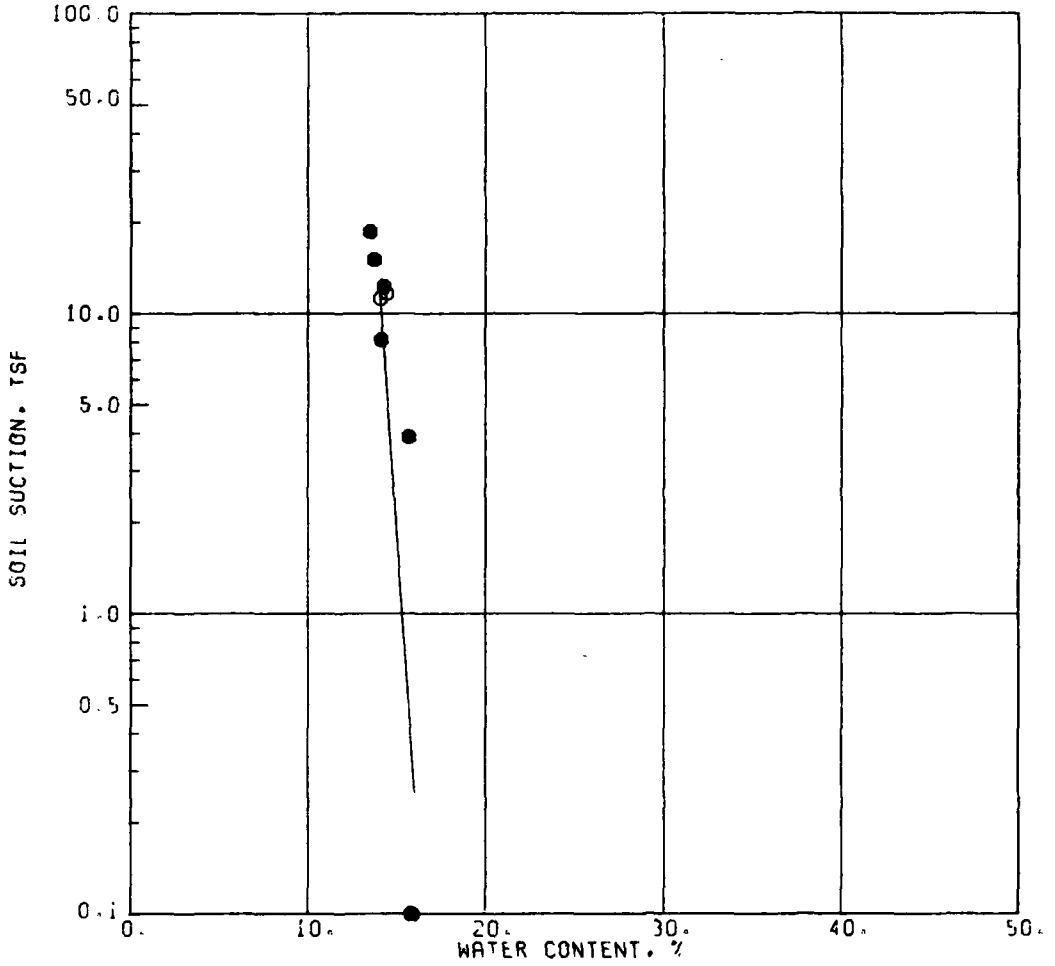
SITE: BILLINGS, MT
BOR: U-2 SAM: 4 DEP: 6.7-



SOIL SUCTION VERSUS WATER CONTENT RELATIONSHIP USING FILTER PAPER & MCQUEEN/MILLER '68 CALIBRATION CURVE

LOG SOIL SUCTION = 14.0152 -0.9136 * WATER CONTENT

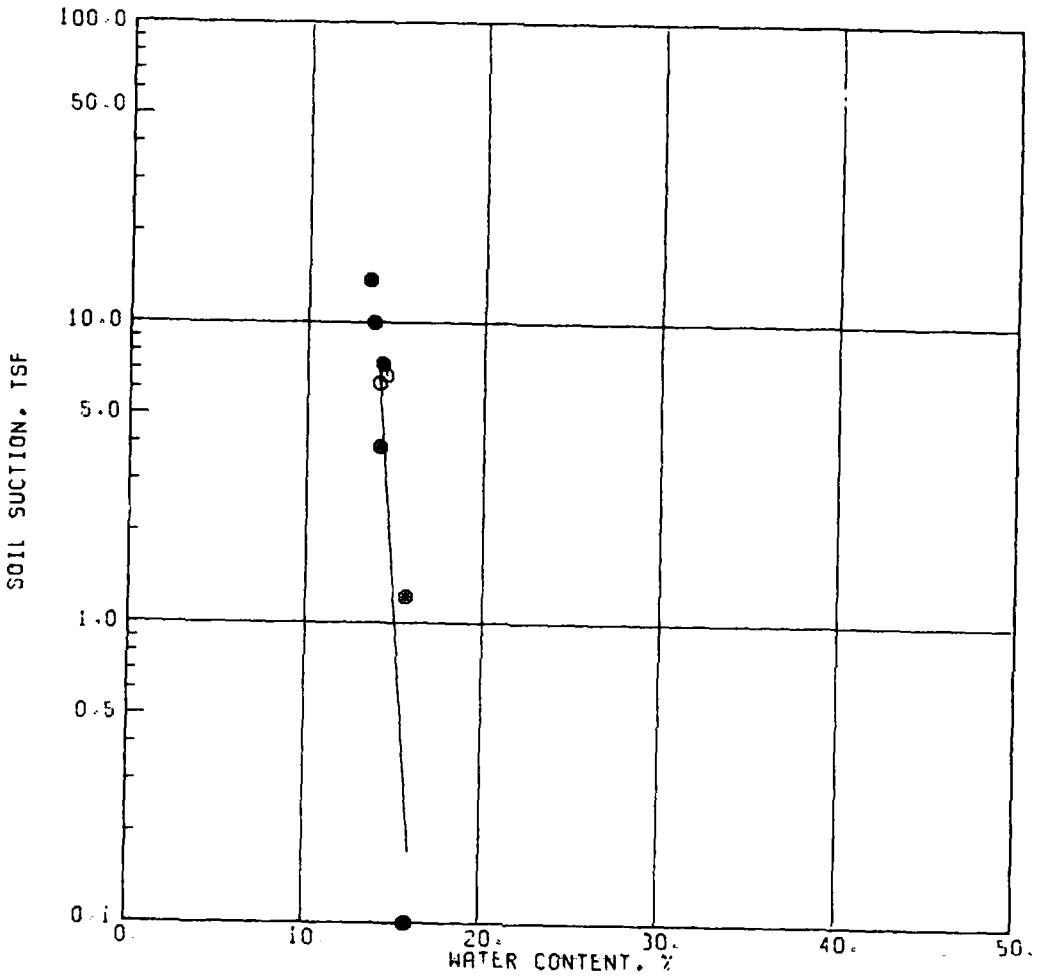
SITE: BILLINGS, MT
BOR: U-2 SAM: 4 DEP: 6.7-



SOIL SUCTION VERSUS WATER CONTENT RELATIONSHIP USING FILTER PAPER & MILLER '78 CALIBRATION CURVE

LOG SOIL SUCTION = 12.9707 -0.8477 * WATER CONTENT

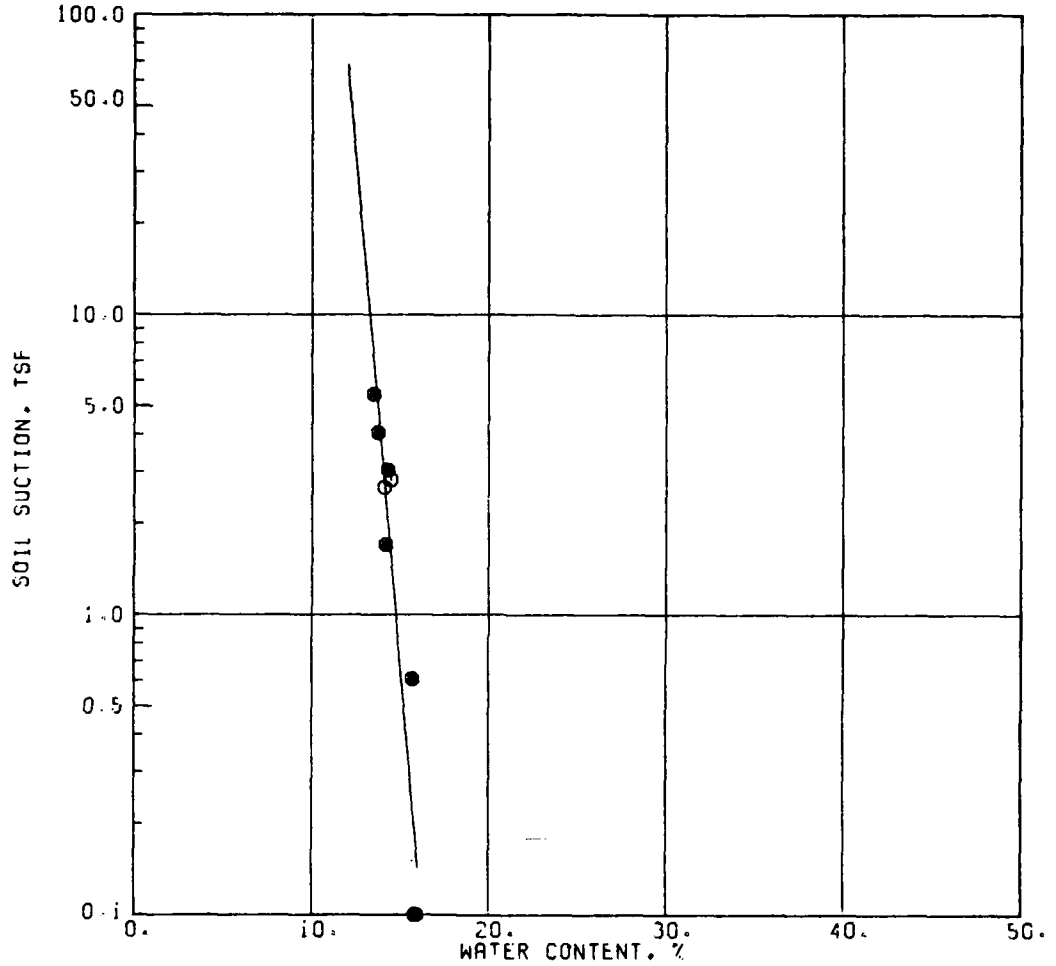
SITE: BILLINGS, MT
BOR: U-2 SAM: 4 DEP: 6.7-



SOIL SUCTION VERSUS WATER CONTENT RELATIONSHIP USING FILTER PAPER & W.E.S.-I '79 CALIBRATION CURVE

LOG SOIL SUCTION = 12.3750 -0.8212 * WATER CONTENT

SITE: BILLINGS, MT
BOR: U-2 SAM: 4 DEP: 6.7-



SOIL SUCTION VERSUS WATER CONTENT RELATIONSHIP USING FILTER PAPER & W.E.S.-II '79 CALIBRATION CURVE

LOG SOIL SUCTION = 9.8941 -0.6711 * WATER CONTENT

SITE: BILLINGS, MT
BOR: U-2 SAM: 4 DEP: 6.7-

- TABLE 1 - SOIL SUCTION AND WATER CONTENT DATA USING THERMOCOUPLE PSYCHROMETER

SITE: RELIANCE, SD
BOR: U-1 SAM: 5 DEP: 8.0-10.6 FT

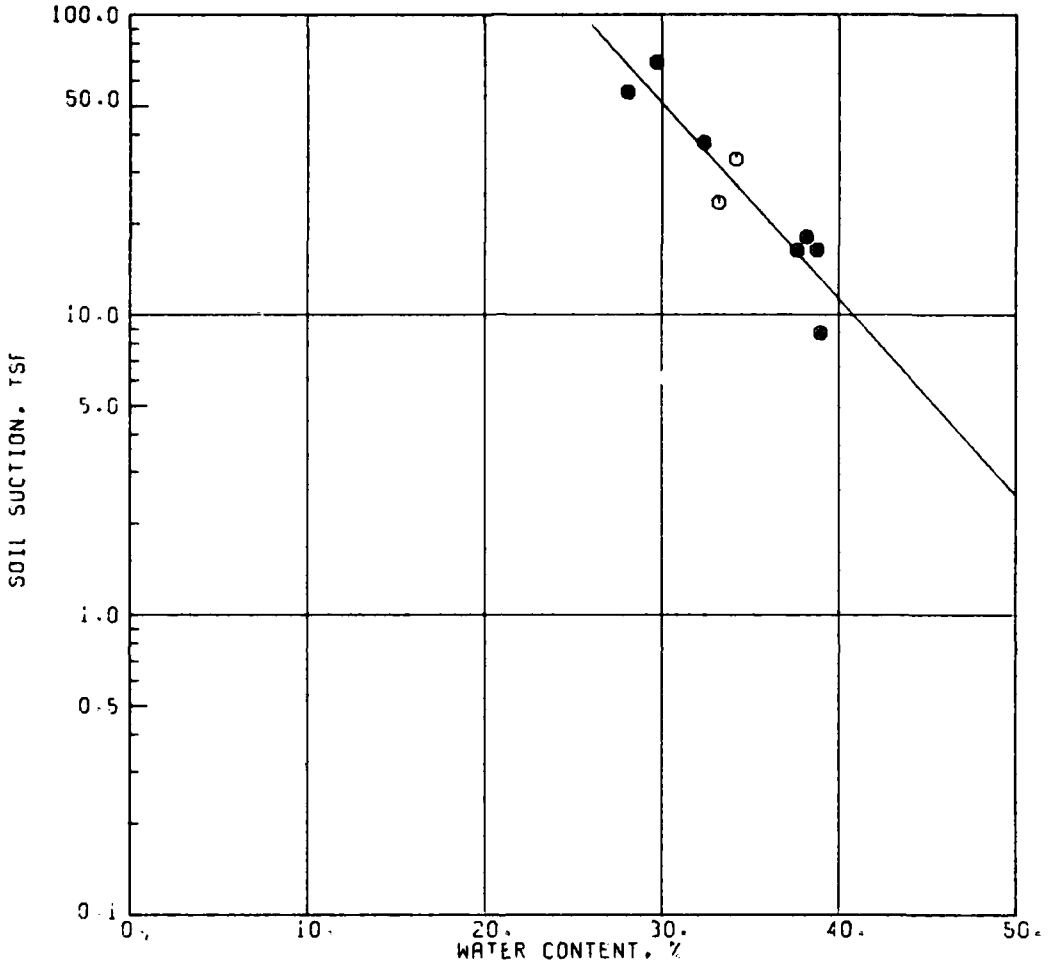
SPECIMEN NUMBER	SOIL SUCTION, TSF	WATER CONTENT %
1	23.6	33.2
2	32.9	34.2
3	16.3	37.6
4	16.4	38.8
5	18.1	38.1
6	8.7	38.9
7	37.4	32.4
8	69.3	29.7
9	55.1	28.1

LOG SOIL SUCTION = 3.6686 -0.0654 * WC

- TABLE 2 - SOIL SUCTION AND WATER CONTENT DATA USING FILTER PAPER AND CALIBRATION CURVES

SITE: RELIANCE, SD
BOR: U-1 SAM: 5 DEP: 8.0-10.6 FT

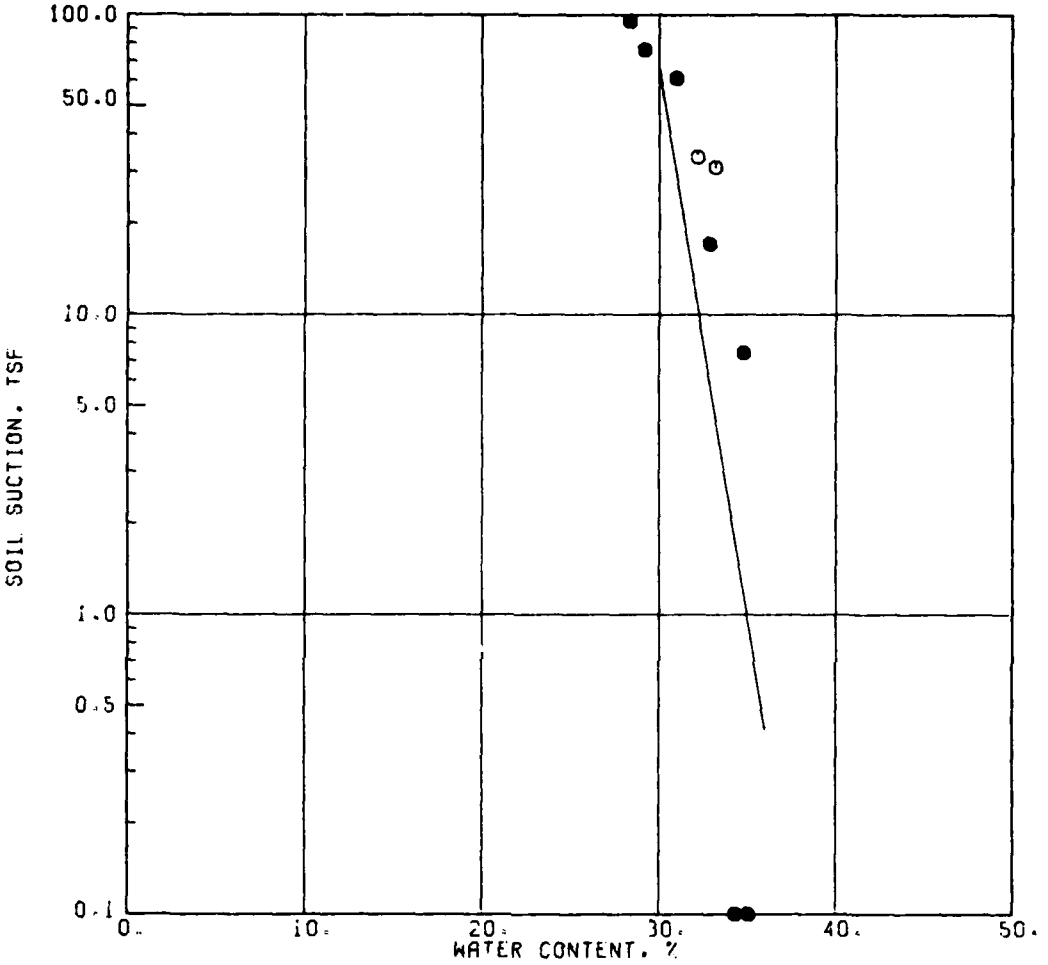
SPECIMEN NUMBER	MOISTURE CONTENT FILTER PAPER %	- - - SOIL SUCTION, TSF - - - McQUEEN/ MILLER 1968	MILLER 1978	W.E.S. I 1979	W.E.S. II 1979	Soil Water Content %
1	24.41	31.0	20.9	16.3	6.3	33.20
2	23.94	33.5	22.3	18.0	6.9	32.18
3	27.96	17.2	12.9	7.8	3.2	37.86
4	32.99	7.4	6.5	2.7	1.3	34.78
5	83.50	0.1	0.1	0.1	0.1	34.32
6	98.31	0.1	0.1	0.1	0.1	35.06
7	20.30	61.4	36.5	38.7	13.7	30.97
8	19.00	76.3	43.6	50.8	17.6	29.19
9	17.67	95.2	52.2	67.1	22.6	28.33



SOIL SUCTION VERSUS WATER CONTENT RELATIONSHIP USING THERMOCOUPLE PSYCHROMETERS

LOG SOIL SUCTION = 3.6686 -0.0654 * WATER CONTENT

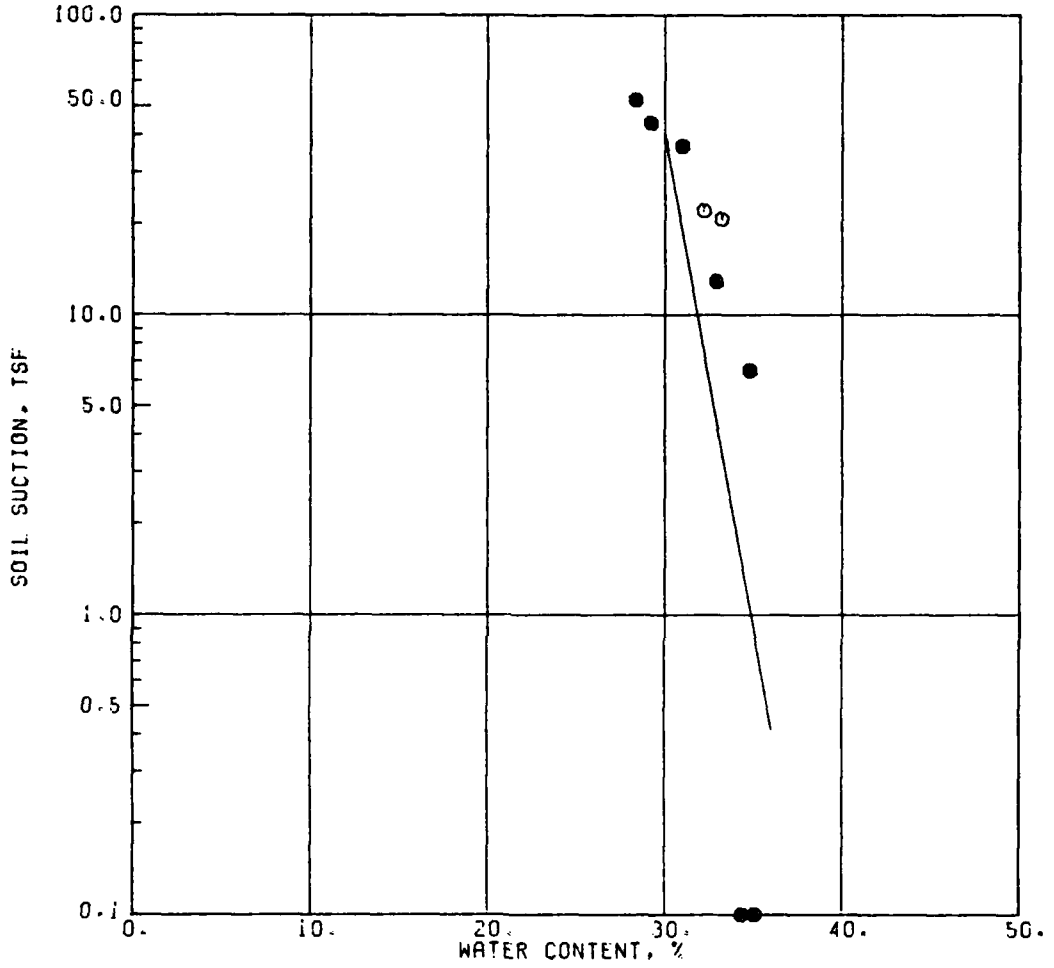
SITE: RELIANCE, SD
BOR: U-1 SAM: 5 DEP: 8.0-



SOIL SUCTION VERSUS WATER CONTENT RELATIONSHIP USING FILTER PAPER & MCQUEEN/MILLER '68 CALIBRATION CURVE

LOG SOIL SUCTION = 12.9098 -0.3693 * WATER CONTENT

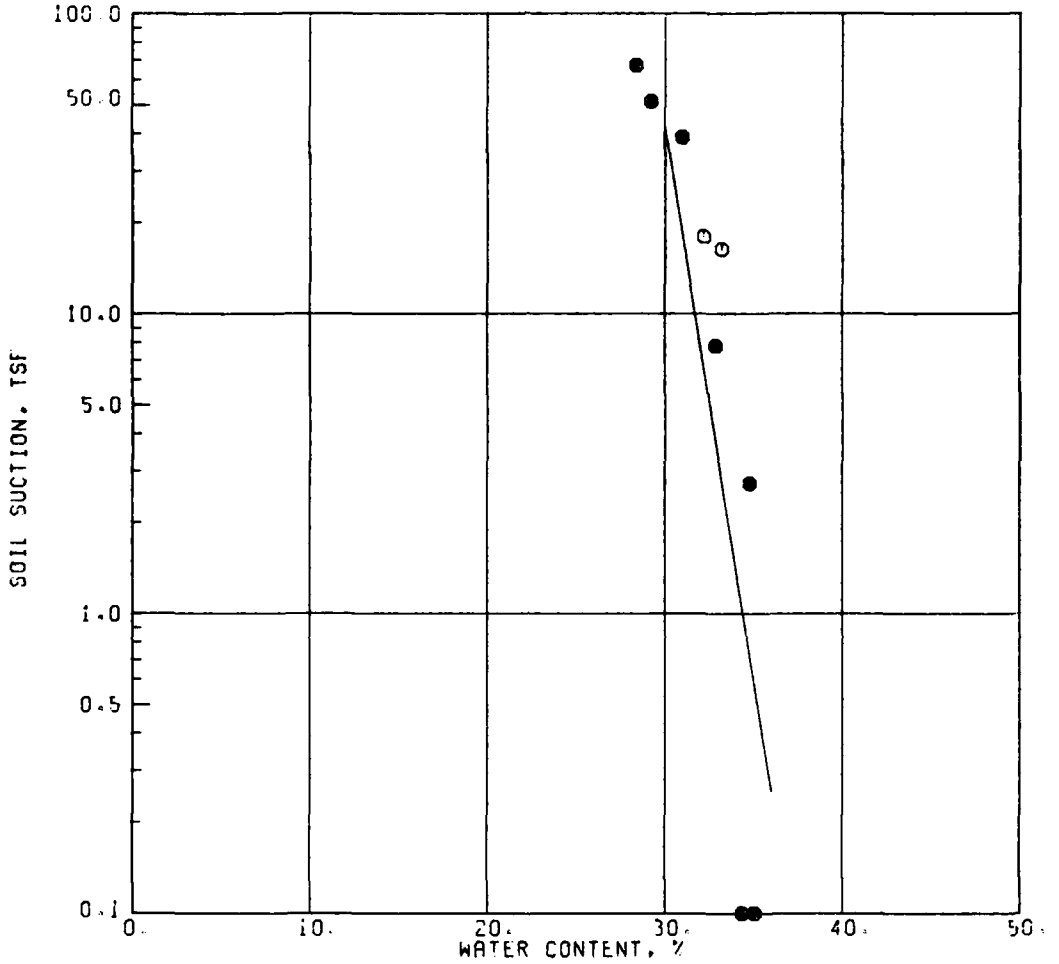
SITE: RELIANCE, SD
BOR: U-1 SAM: 5 DEP: 8.0-



SOIL SUCTION VERSUS WATER CONTENT RELATIONSHIP USING FILTER PAPER & MILLER '78 CALIBRATION CURVE

LOG SOIL SUCTION = 11.5253 -0.3308 * WATER CONTENT

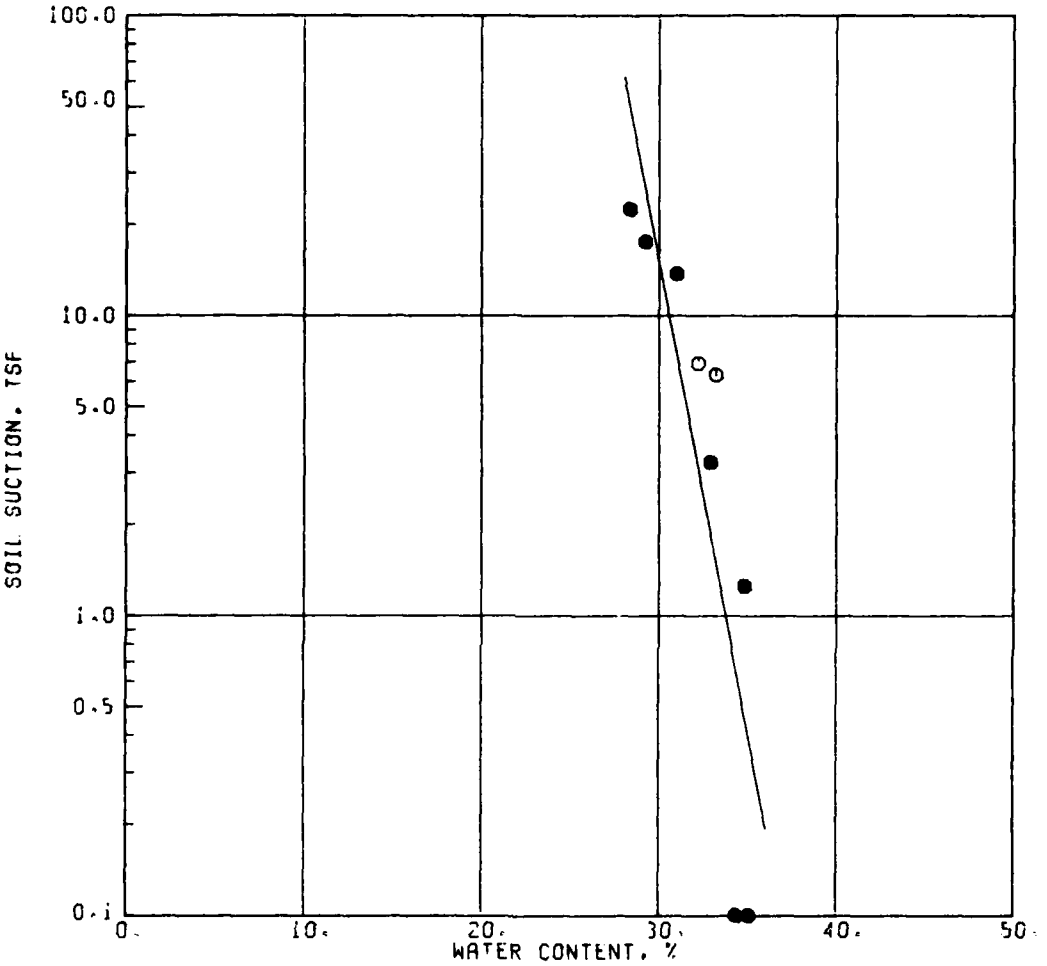
SITE: RELIANCE, SD
BOR: U-1 SAM: 5 DEP: 8.0-



SOIL SUCTION VERSUS WATER CONTENT RELATIONSHIP USING FILTER PAPER & W.E.S.-I '79 CALIBRATION CURVE

LOG SOIL SUCTION = 12.7310 -0.3701 * WATER CONTENT

SITE: RELIANCE, SD
BOR: U-1 SAM: 5 DEP: 8.0-



SOIL SUCTION VERSUS WATER CONTENT RELATIONSHIP USING FILTER PAPER & W.E.S.-II '79 CALIBRATION CURVE

LOG SOIL SUCTION = 10.5812 -0.3137 * WATER CONTENT

SITE: RELIANCE, SD
BOR: U-1 SAM: 5 DEP: 8.0-

- TABLE 1 - SOIL SUCTION AND WATER CONTENT DATA
USING THERMOCOUPLE PSYCHROMETER

SITE: FLAGSTAFF, AZ STA 672
BOR: U-1 SAM: 8 DEP: 8.35-9.75 FT

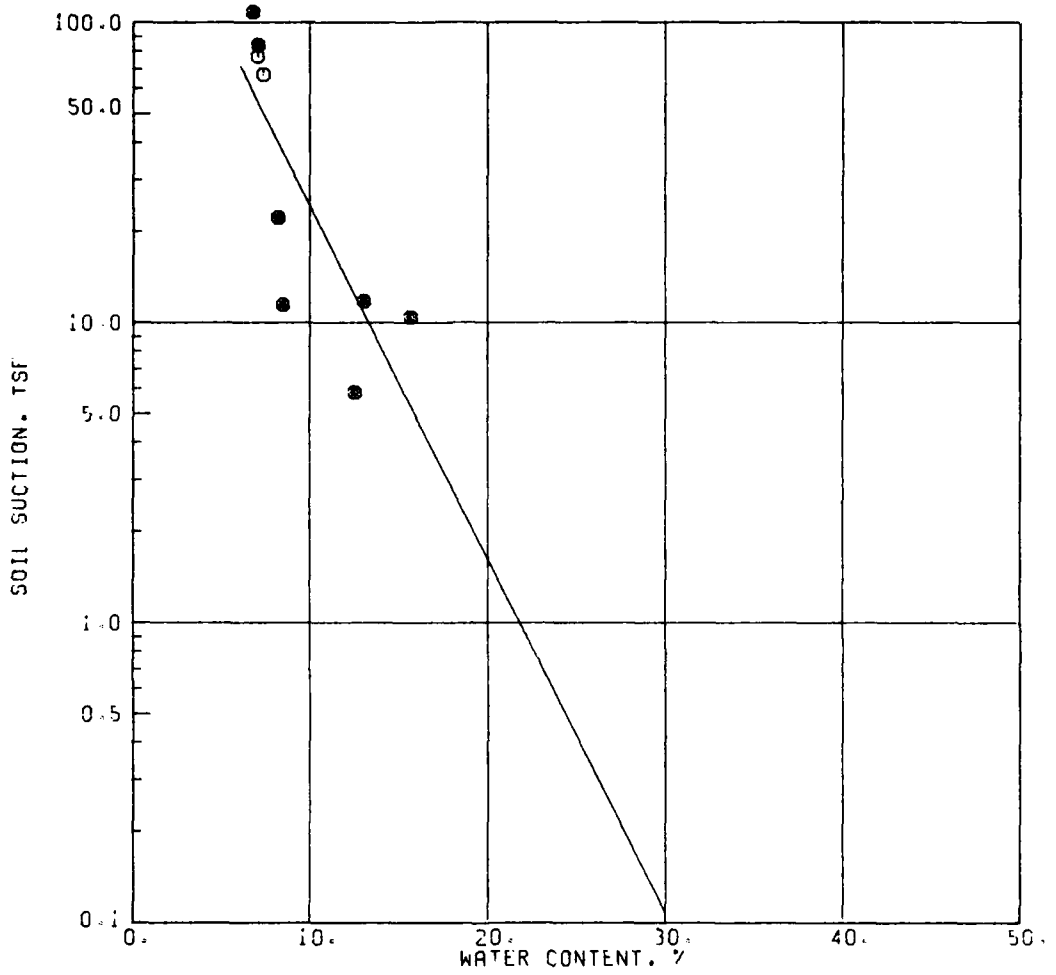
SPECIMEN NUMBER	SOIL SUCTION, TSF	WATER CONTENT %
1	76.9	7.1
2	66.8	7.4
3	22.4	8.2
4	10.4	15.7
5	11.4	8.5
6	5.8	12.5
7	11.8	13.0
8	84.0	7.1
9	108.0	6.7

LOG SOIL SUCTION = 2.5637 -0.1178 * WC

- TABLE 2 - SOIL SUCTION AND WATER CONTENT DATA
USING FILTER PAPER AND CALIBRATION CURVES

SITE: FLAGSTAFF, AZ STA 672
BOR: U-1 SAM: 8 DEP: 8.35-9.75 FT

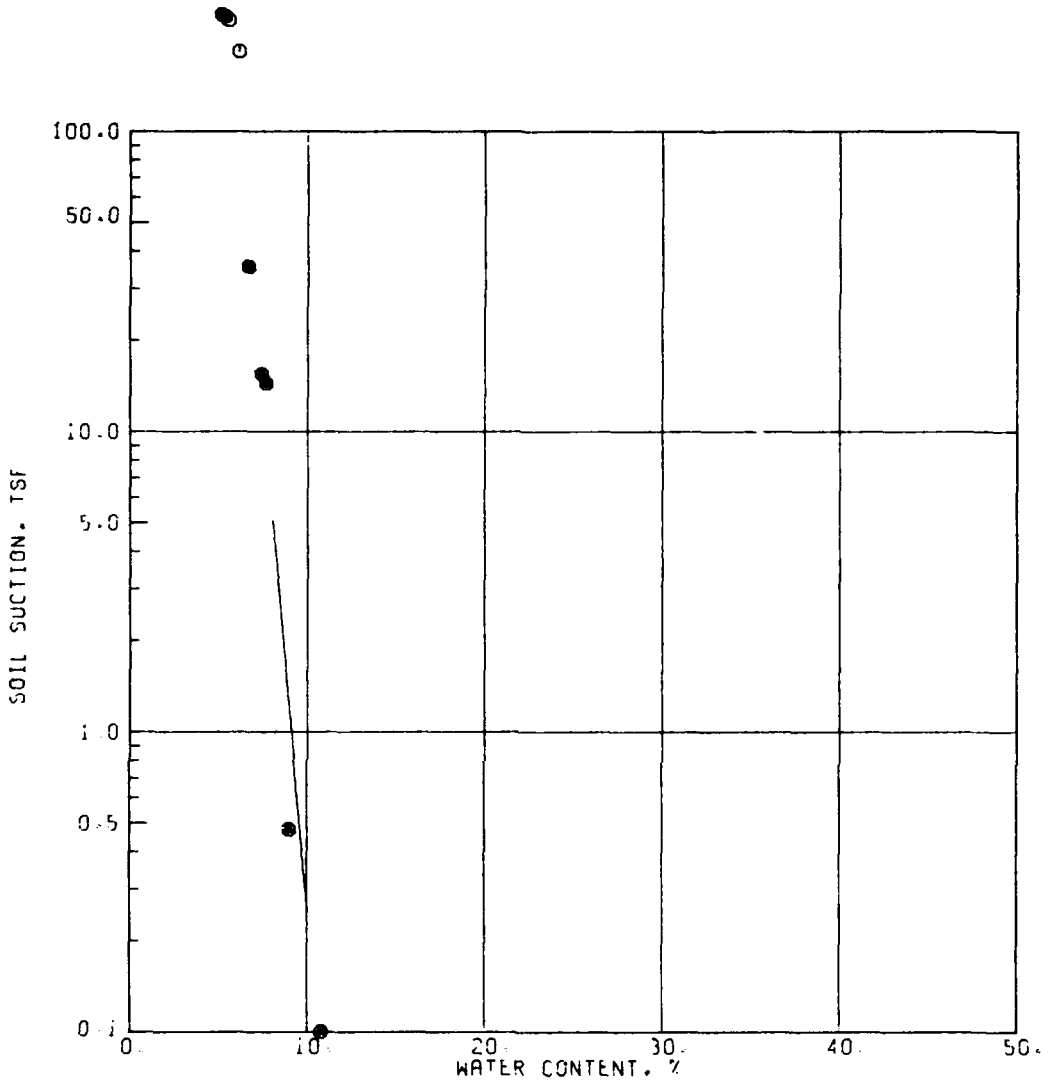
SPECIMEN NUMBER	MOISTURE CONTENT FILTER PAPER %	- - - SOIL SUCTION, TSF - - - McQUEEN/ MILLER 1968	MILLER 1978	W.E.S. I 1979	W.E.S. II 1979	SOIL WATER CONTENT %
1	13.71	184.3	89.4	154.1	47.8	6.16
2	12.27	233.9	108.7	208.1	62.6	5.55
3	23.64	35.3	23.2	19.2	7.3	6.65
4	28.57	15.5	11.9	6.8	2.9	7.39
5	29.00	14.4	11.2	6.3	2.7	7.62
6	49.55	0.5	0.7	0.1	0.1	8.96
7	69.77	0.1	0.1	0.1	0.1	10.78
8	12.11	240.4	111.1	215.4	64.6	5.31
9	12.02	244.0	112.5	219.4	65.7	5.11



SOIL SUCTION VERSUS WATER CONTENT RELATIONSHIP USING THERMOCOUPLE PSYCHROMETERS

LOG SOIL SUCTION = 2.5637 -0.1178 * WATER CONTENT

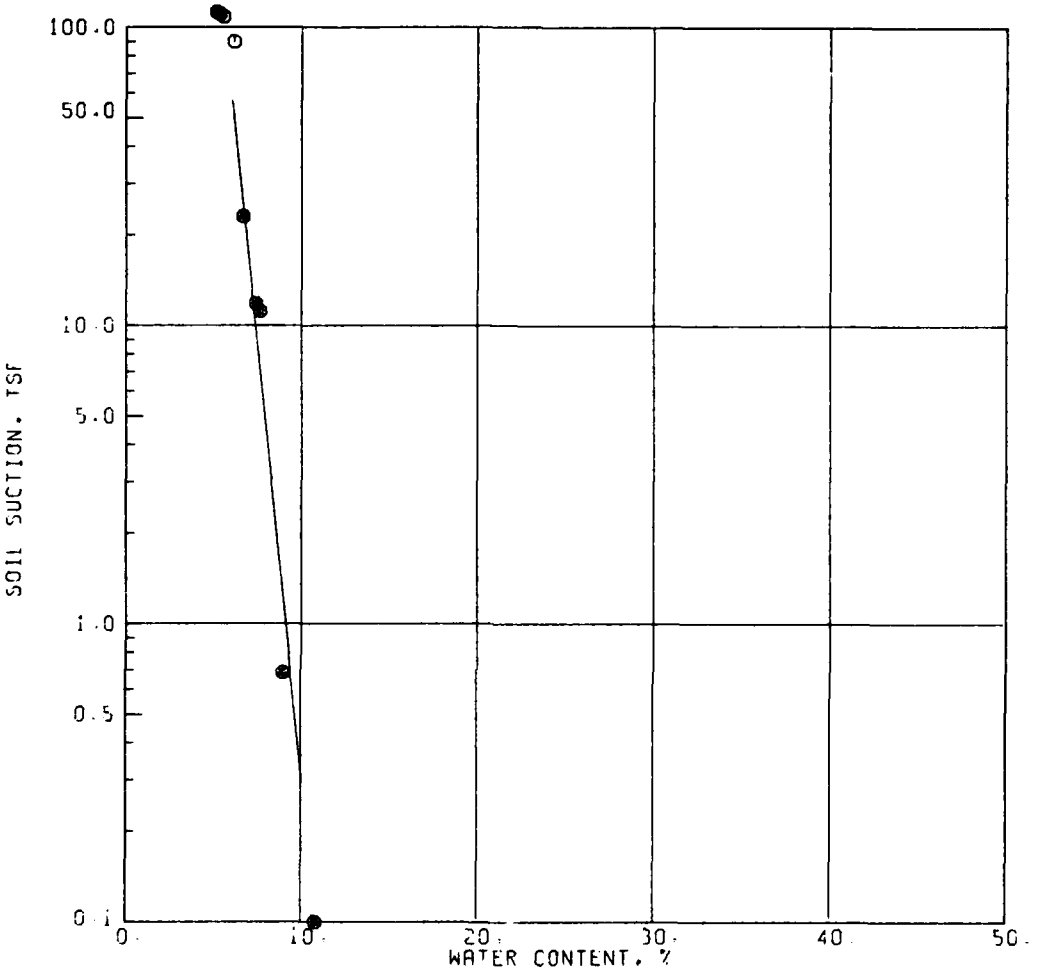
SITE: FLAGSTAFF, AZ STA 672
BOR: U-1 SAM: 8 DEP: 8.35



SOIL SUCTION VERSUS WATER CONTENT RELATIONSHIP USING FILTER PAPER & MCQUEEN/MILLER '68 CALIBRATION CURVE

LOG SOIL SUCTION = 5.9641 -0.6564 * WATER CONTENT

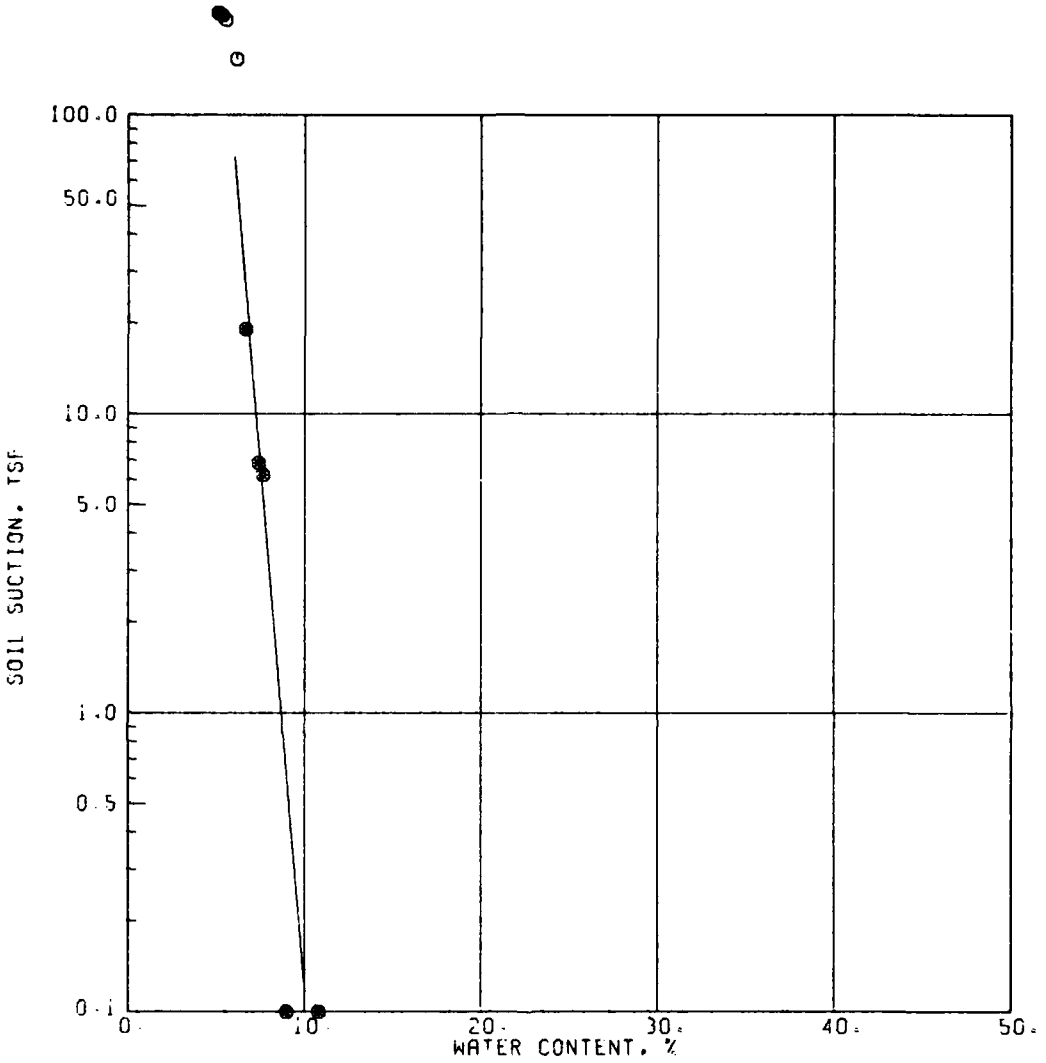
SITE: FLAGSTAFF, AZ STA 672
BOR: U-1 SAM: 8 DEP: 8.35



SOIL SUCTION VERSUS WATER CONTENT RELATIONSHIP USING FILTER PAPER & MILLER '78 CALIBRATION CURVE

LOG SOIL SUCTION = 5.2072 -0.5738 * WATER CONTENT

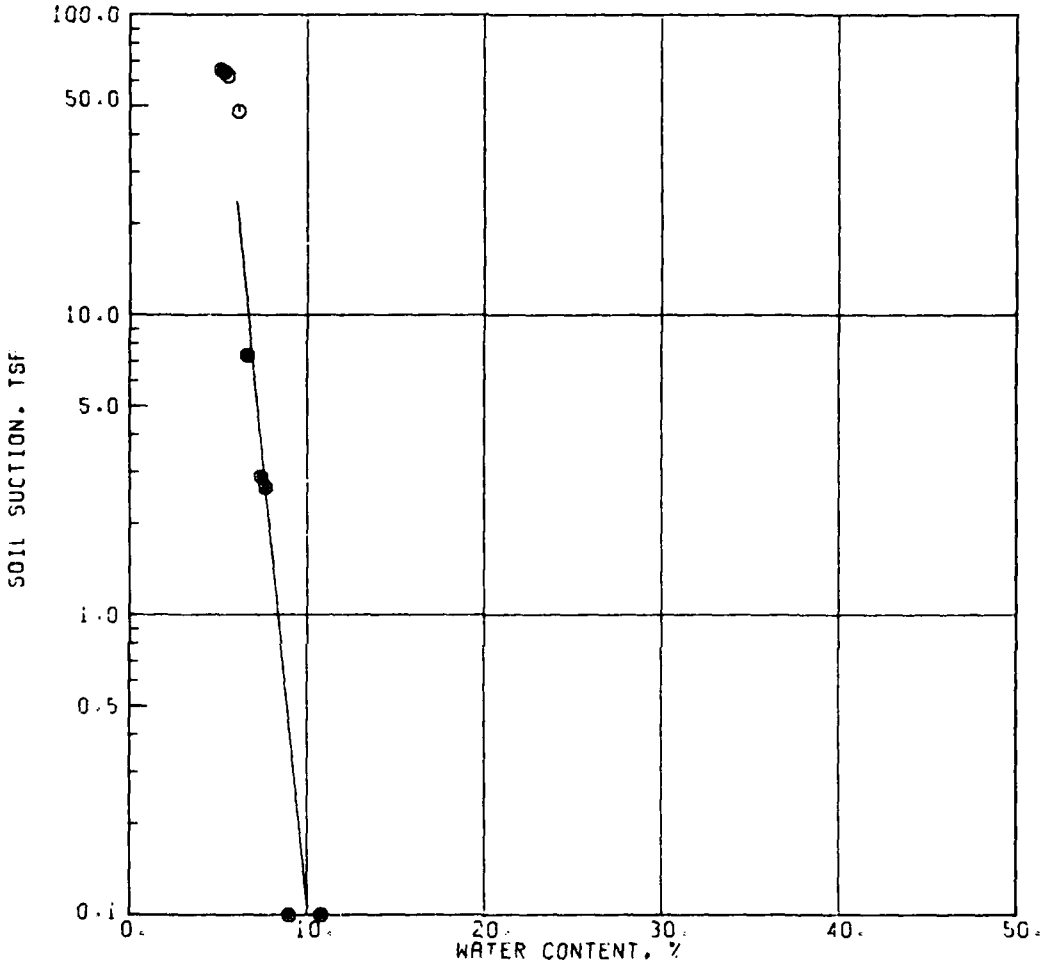
SITE: FLAGSTAFF, AZ SITA 672
BOR: U-1 SAM: 8 DEP: 8.35



SOIL SUCTION VERSUS WATER CONTENT RELATIONSHIP USING FILTER PAPER & W.E.S.-I '79 CALIBRATION CURVE

LOG SOIL SUCTION = 6.0523 -0.6985 * WATER CONTENT

SITE: FLAGSTAFF, AZ STA 672
BOR: U-1 SAM: 8 DEP: 8.35



SOIL SUCTION VERSUS WATER CONTENT RELATIONSHIP USING FILTER PAPER & W.E.S.-II '79 CALIBRATION CURVE

LOG SOIL SUCTION = 4.9299 -0.5905 * WATER CONTENT

SITE: FLAGSTAFF, AZ STA 672
BOR: U-1 SAM: 8 DEP: 8.35

- TABLE 1 - SOIL SUCTION AND WATER CONTENT DATA
USING THERMOCOUPLE PSYCHROMETER

SITE: FLAGSTAFF, AZ STA 861
BOR: U-3 SAM: 7 DEP: 11.7-13.7 FT

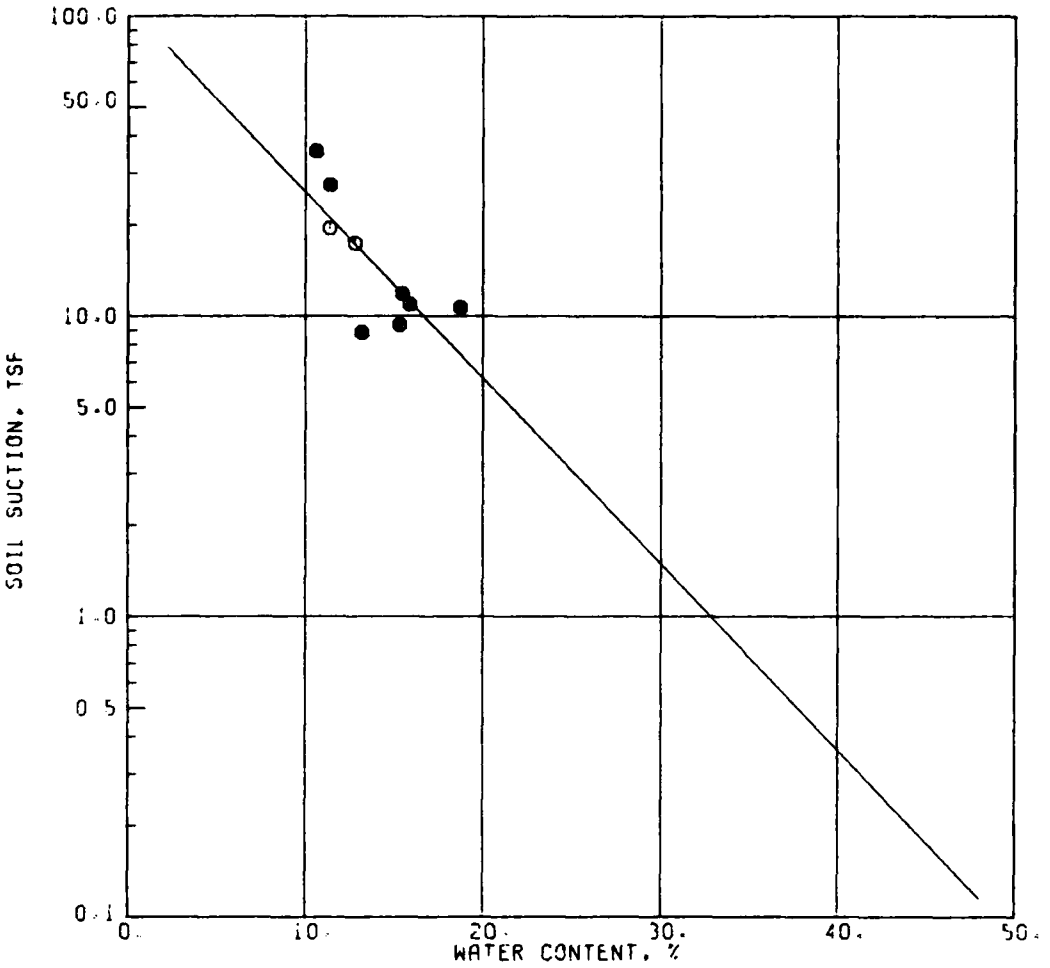
SPECIMEN NUMBER	SOIL SUCTION, TSF	WATER CONTENT %
1	19.7	11.4
2	17.5	12.8
3	8.8	13.2
4	11.9	15.5
5	9.4	15.3
6	10.9	15.9
7	10.7	18.7
8	27.4	11.4
9	35.5	10.6

LOG SOIL SUCTION = 2.0336 -0.0619 * WC

- TABLE 2 - SOIL SUCTION AND WATER CONTENT DATA
USING FILTER PAPER AND CALIBRATION CURVES

SITE: FLAGSTAFF, AZ STA 861
BOR: U-3 SAM: 7 DEP: 11.7-13.7 FT

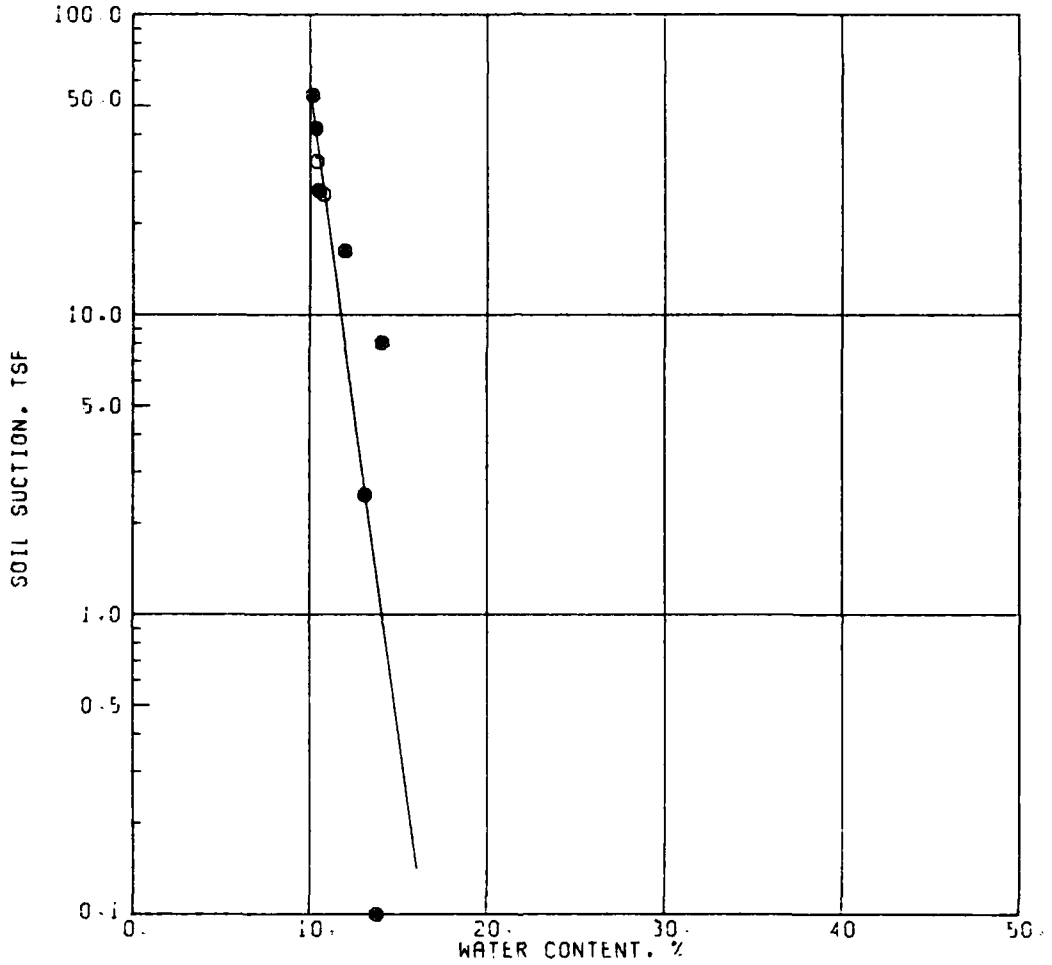
SPECIMEN NUMBER	MOISTURE CONTENT FILTER PAPER %	- - - SOIL SUCTION, TSF - - - McQUEEN/ MILLER 1968	MILLER 1978	W.E.S. I 1979	W.E.S. II 1979	SOIL WATER CONTENT %
1	25.65	25.2	17.6	12.6	5.0	10.81
2	24.14	32.5	21.7	17.3	6.7	10.40
3	25.47	26.0	18.1	13.1	5.2	10.40
4	28.26	16.3	12.4	7.3	3.1	11.95
5	39.51	2.5	2.7	0.7	0.4	13.11
6	32.50	8.1	7.0	3.0	1.4	14.04
7	130.66	0.1	0.1	0.1	0.1	13.79
8	21.08	54.0	32.9	32.9	11.9	10.14
9	22.61	41.9	26.7	23.9	8.9	10.31



SOIL SUCTION VERSUS WATER CONTENT RELATIONSHIP USING THERMOCOUPLE PSYCHROMETERS

LOG SOIL SUCTION = 2.0336 -0.0619 * WATER CONTENT

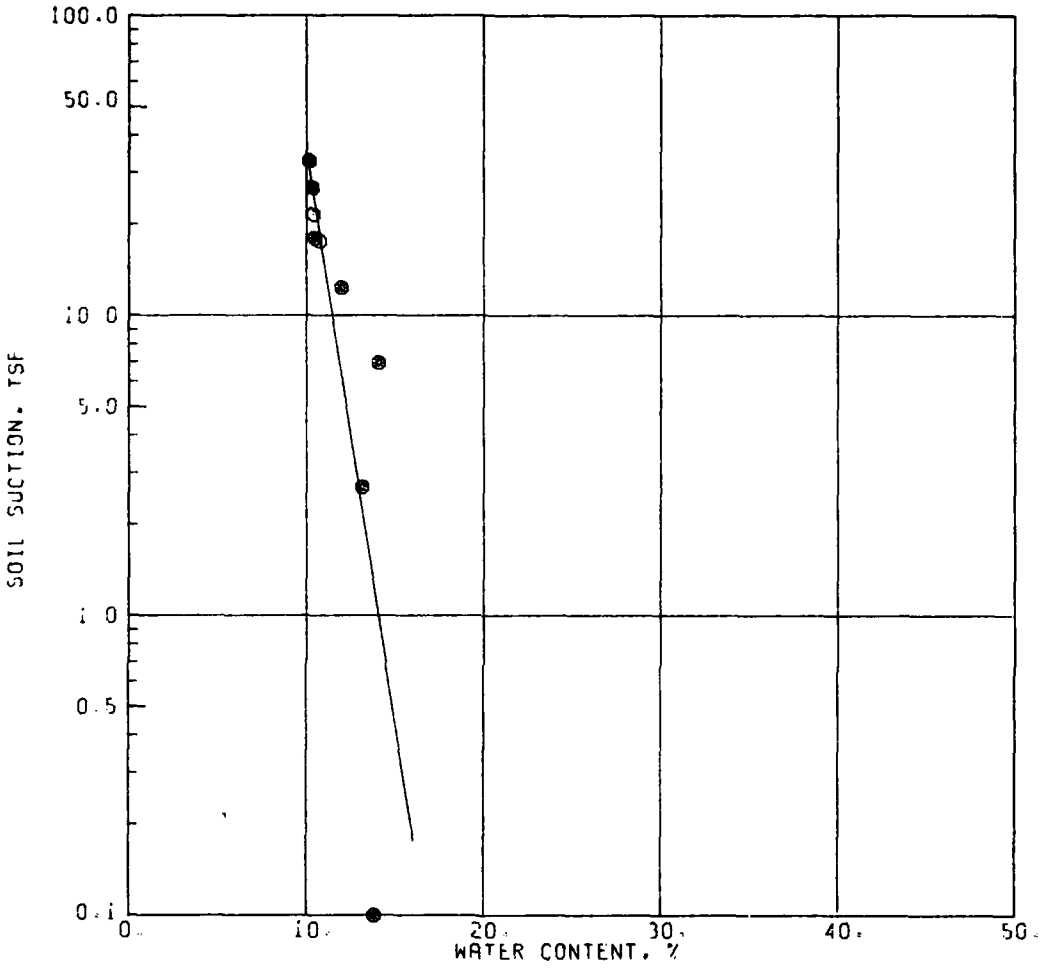
SITE: FLAGSTAFF, AZ STA 861
BOR: U-3 SAM: 7 DEP: 11.7



SOIL SUCTION VERSUS WATER CONTENT RELATIONSHIP USING FILTER PAPER & MCQUEEN/MILLER '68 CALIBRATION CURVE

LOG SOIL SUCTION = 6.0542 -0.4312 * WATER CONTENT

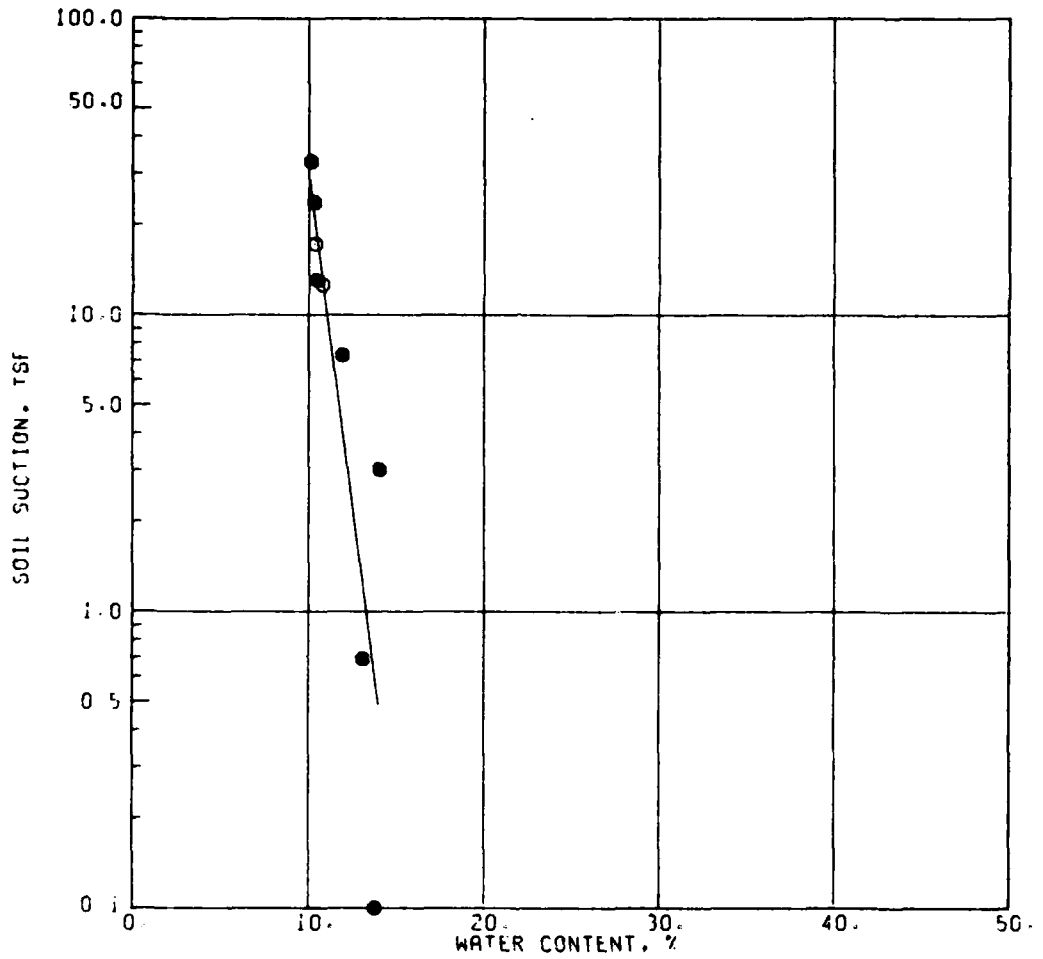
SITE: FLAGSTAFF, AZ STA 861
BOR: U-3 SAM: 7 DEP: 11.7



SOIL SUCTION VERSUS WATER CONTENT RELATIONSHIP USING FILTER PAPER & MILLER '78 CALIBRATION CURVE

LOG SOIL SUCTION = 5.3621 -0.3819 * WATER CONTENT

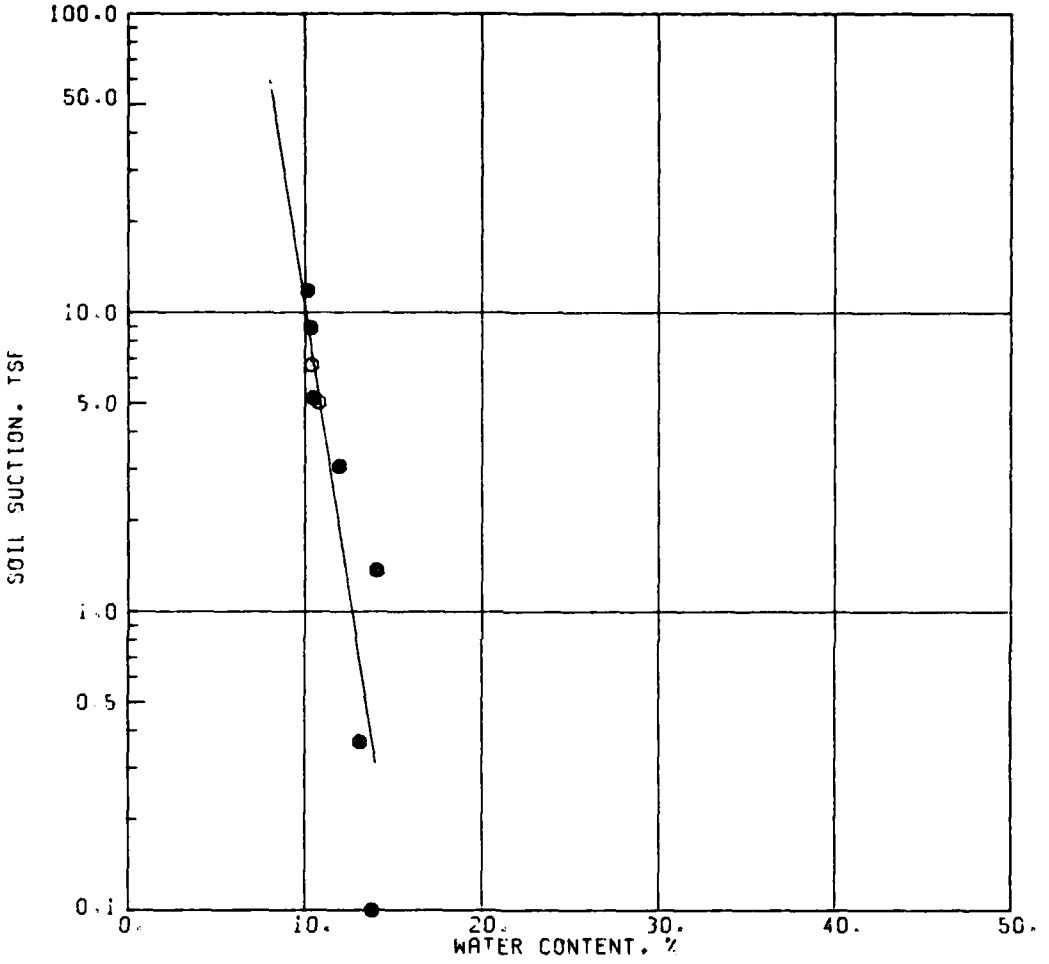
SITE: FLAGSTAFF, AZ STA 861
BOR: U-3 SAM: 7 DEP: 11.7



SOIL SUCTION VERSUS WATER CONTENT RELATIONSHIP USING FILTER PAPER & W.E.S.-I '79 CALIBRATION CURVE

LOG SOIL SUCTION = 5.9315 -0.4461 * WATER CONTENT

SITE: FLAGSTAFF, AZ STA 861
BOR: U-3 SAM: 7 DEP: 11.7



SOIL SUCTION VERSUS WATER CONTENT RELATIONSHIP USING FILTER PAPER & W.E.S.-II '79 CALIBRATION CURVE

LOG SOIL SUCTION = 4.8377 -0.3817 * WATER CONTENT

SITE: FLAGSTAFF, AZ STA 861
BOR: U-3 SAM: 7 DEP: 11.7

- TABLE 1 - SOIL SUCTION AND WATER CONTENT DATA
USING THERMOCOUPLE PSYCHROMETER

SITE: LACKLAND AFB, TX
BOR: U-3 SAM: 3 DEP: 5.7-7.3 FT

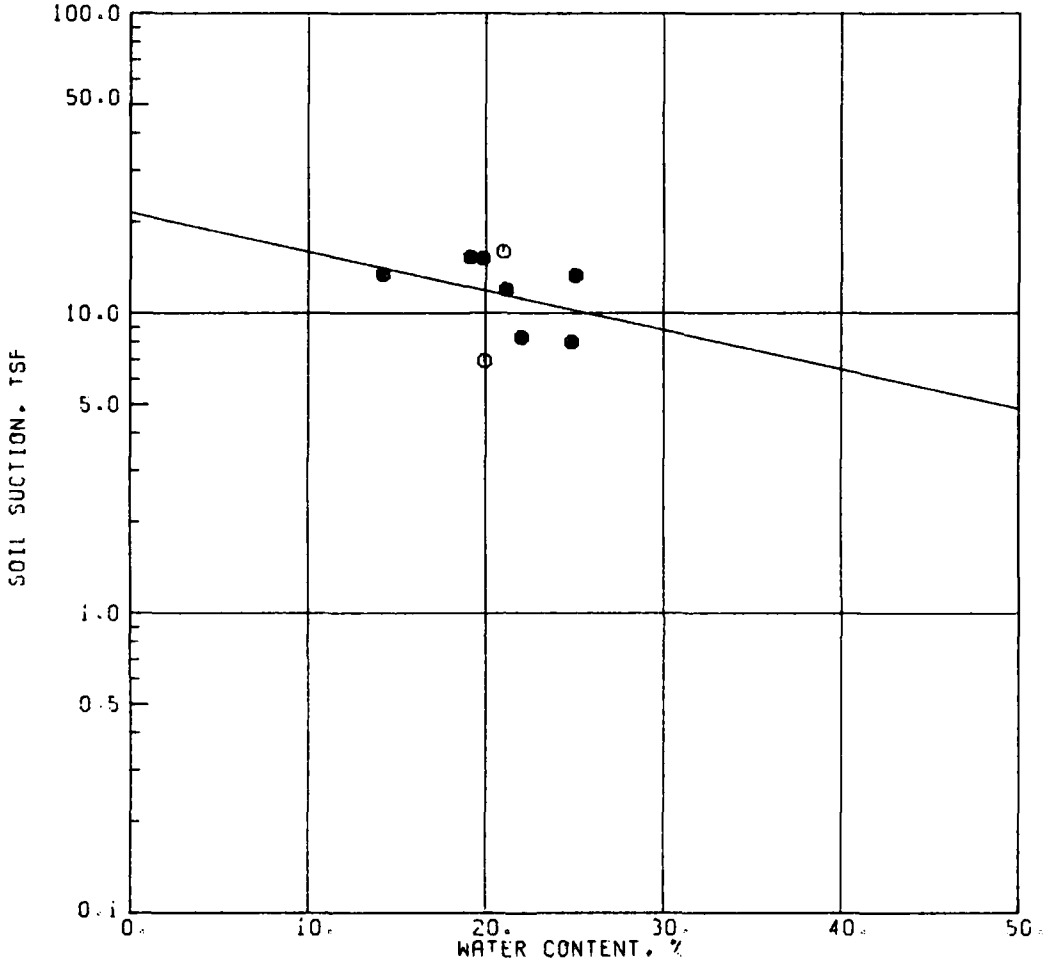
SPECIMEN NUMBER	SOIL SUCTION, TSF	WATER CONTENT %
1	16.0	21.0
2	6.9	20.0
3	12.0	21.2
4	8.3	22.0
5	13.3	25.0
6	8.0	24.8
7	15.2	19.8
8	15.3	19.1
9	13.5	14.2

LOG SOIL SUCTION = 1.3348 -0.0131 * WC

- TABLE 2 - SOIL SUCTION AND WATER CONTENT DATA
USING FILTER PAPER AND CALIBRATION CURVES

SITE: LACKLAND AFB, TX
BOR: U-3 SAM: 3 DEP: 5.7-7.3 FT

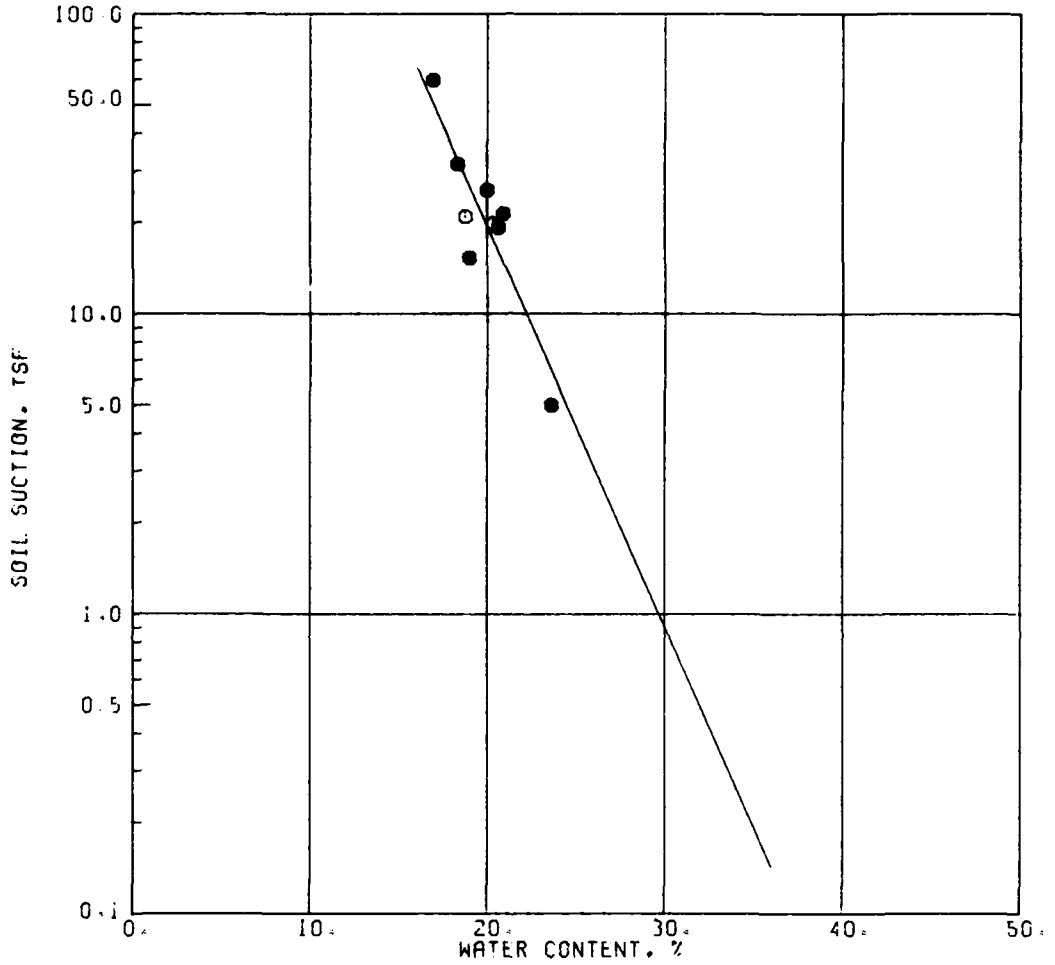
SPECIMEN NUMBER	MOISTURE CONTENT FILTER PAPER %	- - - SOIL SUCTION, TSF - - - McQUEEN/ MILLER 1968	MILLER 1978	W.E.S. I 1979	W.E.S. II 1979	SOIL WATER CONTENT %
1	27.04	20.0	14.6	9.4	3.9	20.37
2	26.73	21.1	15.2	10.1	4.1	18.78
3	28.63	15.4	11.8	6.7	2.9	19.01
4	25.50	25.9	18.0	13.0	5.2	20.00
5	26.60	21.5	15.5	10.3	4.2	20.91
6	35.43	5.0	4.7	1.6	0.8	23.63
7	27.23	19.4	14.2	9.1	3.7	20.65
8	24.30	31.6	21.2	16.7	6.5	18.34
9	20.43	60.1	35.9	37.6	13.4	16.93



SOIL SUCTION VERSUS WATER CONTENT RELATIONSHIP USING THERMOCOUPLE PSYCHROMETERS

LOG SOIL SUCTION = 1.3348 -0.0131 * WATER CONTENT

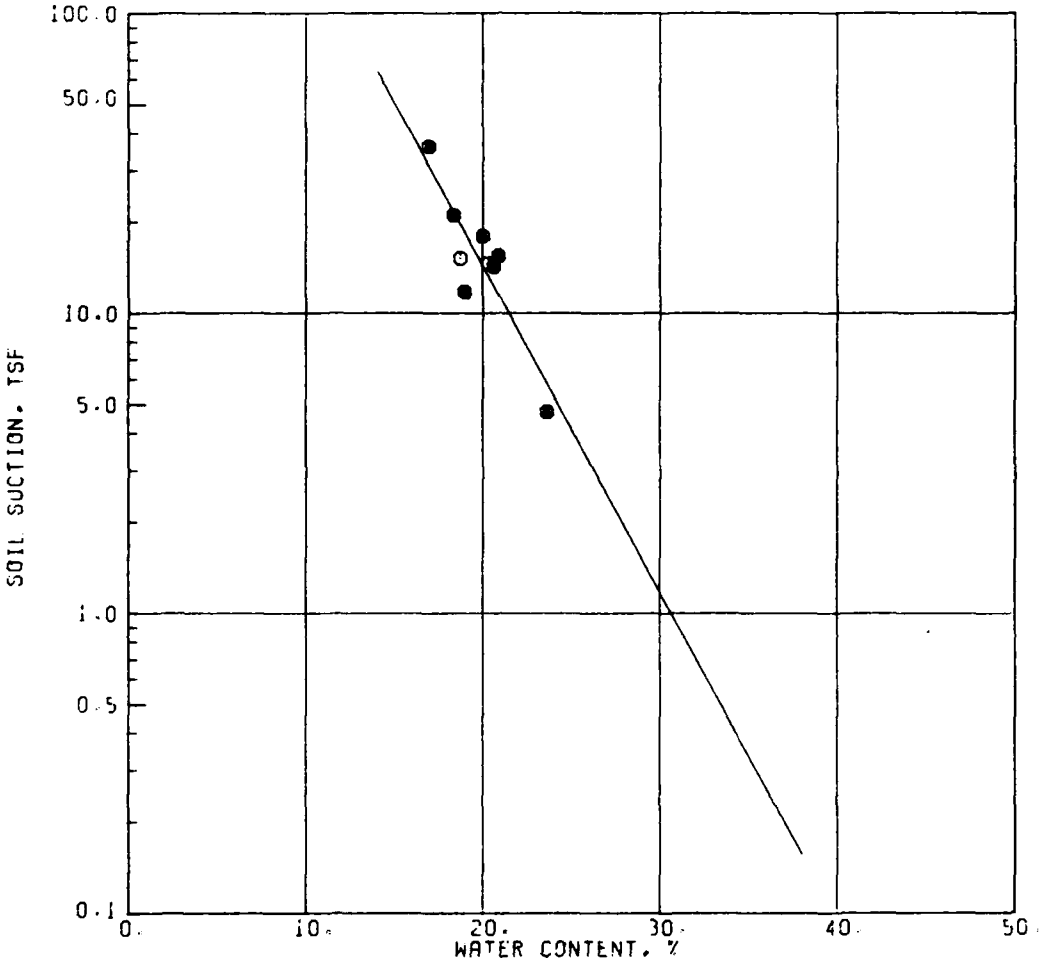
SITE: LACKLAND AFB, TX
BOR: U-3 SAM: 3 DEP: 5.7-



SOIL SUCTION VERSUS WATER CONTENT RELATIONSHIP USING FILTER PAPER & MCQUEEN/MILLER '68 CALIBRATION CURVE

LOG SOIL SUCTION = 3.9628 -0.1335 * WATER CONTENT

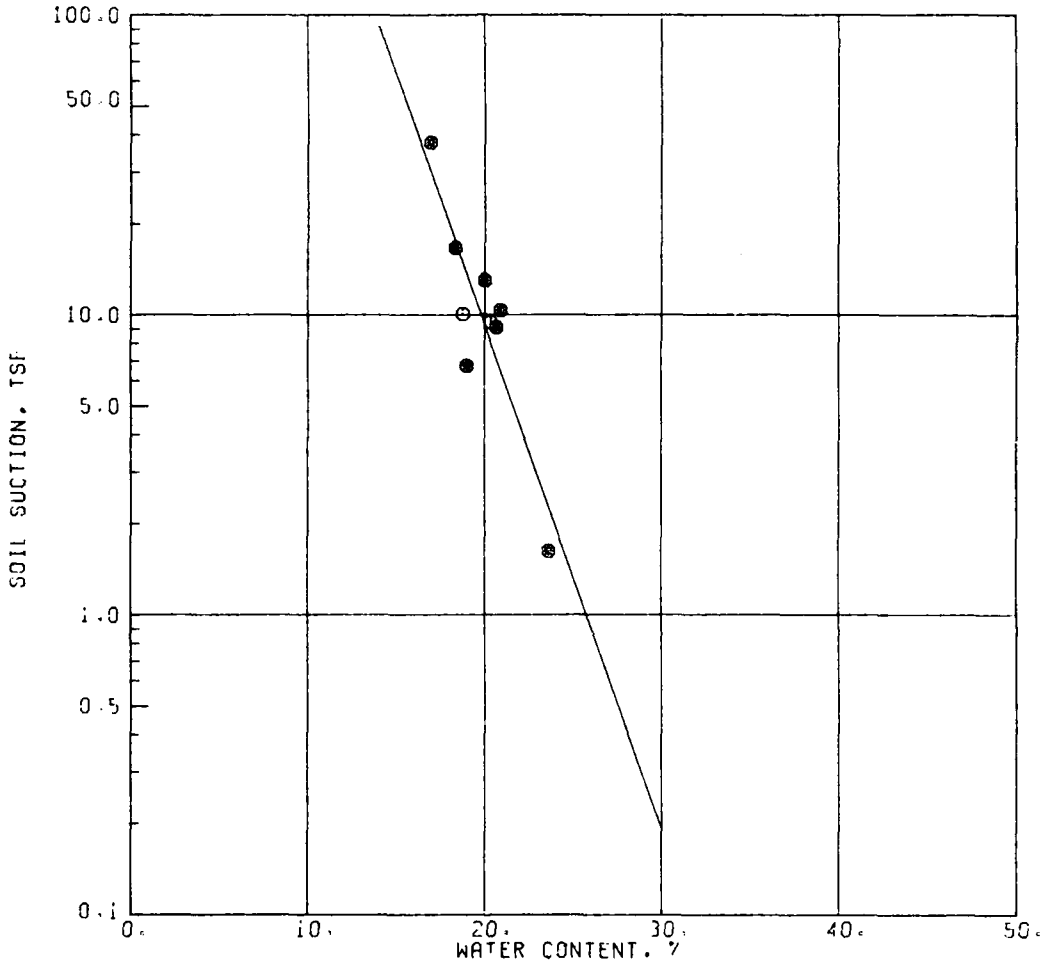
SITE: LACKLAND AFB, TX
BOR: U-3 SAM: 3 DEP: 5.7-



SOIL SUCTION VERSUS WATER CONTENT RELATIONSHIP USING FILTER PAPER & MILLER '78 CALIBRATION CURVE

LOG SOIL SUCTION = 3.3367 -0.1089 * WATER CONTENT

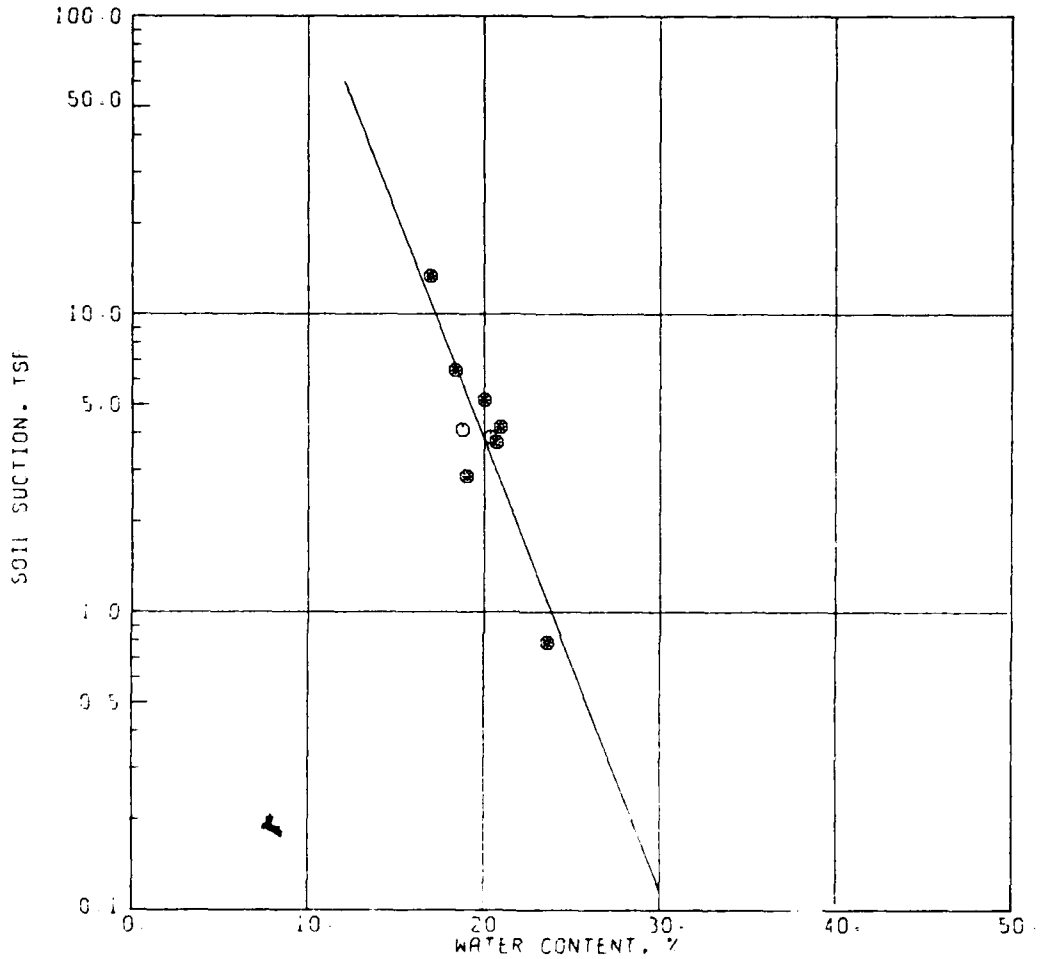
SITE: LACKLAND AFB, TX
BOR: U-3 SAM: 3 DEP: 5.7-



SOIL SUCTION VERSUS WATER CONTENT RELATIONSHIP USING FILTER PAPER & W.E.S.-I '79 CALIBRATION CURVE

LOG SOIL SUCTION = 4.3241 -0.1680 * WATER CONTENT

SITE: LACKLAND AFB, TX
BOR: U-3 SAM: 3 DEP: 5.7-



SOIL SUCTION VERSUS WATER CONTENT RELATIONSHIP USING FILTER PAPER & W.E.S.-II '79 CALIBRATION CURVE

LOG SOIL SUCTION = 3.6042 -0.1514 * WATER CONTENT

SITE: LACKLAND AFB, TX
BOR: U-3 SAM: 3 DEP: 5.7-

- TABLE 1 - SOIL SUCTION AND WATER CONTENT DATA USING THERMOCOUPLE PSYCHROMETER

SITE: FT CARSON, CO
BOR: C-1 SAM: 10 DEP: 9.4-10.6 FT

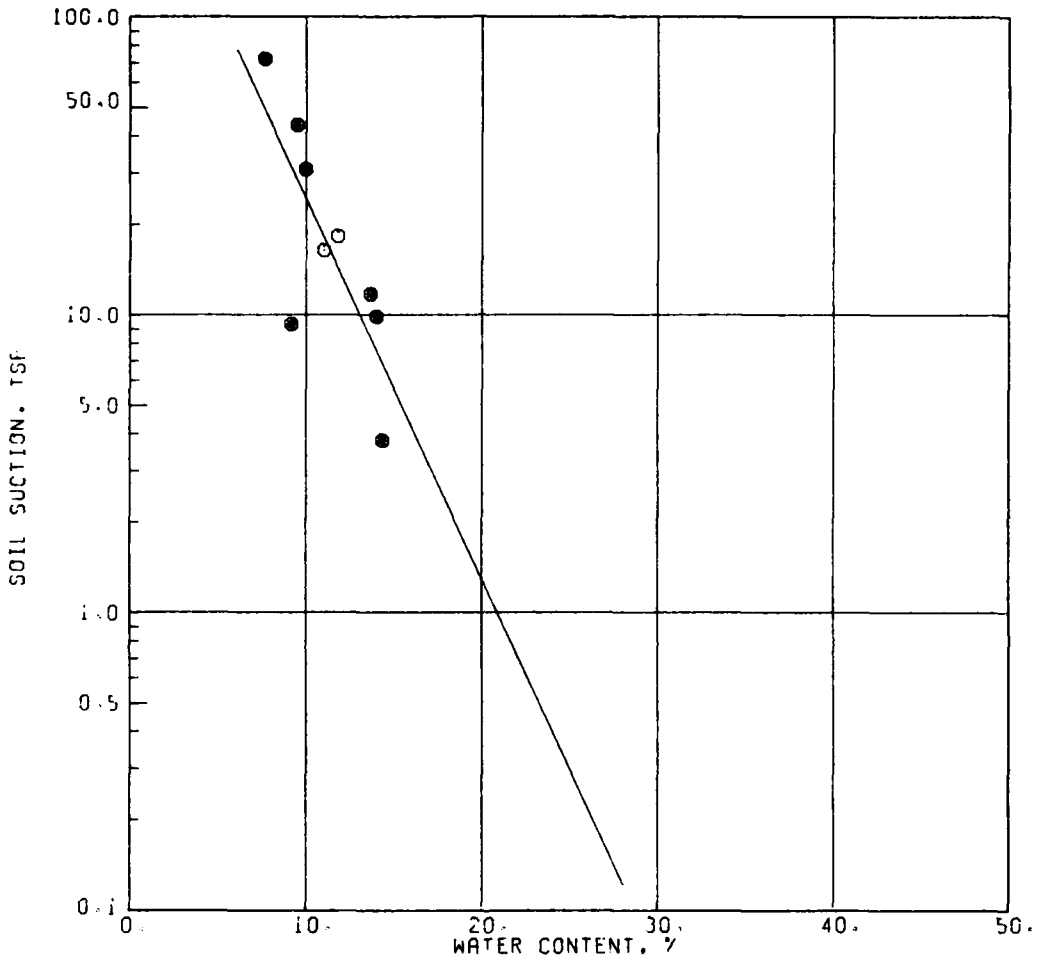
SPECIMEN NUMBER	SOIL SUCTION, TSF	WATER CONTENT %
1	16.4	11.0
2	18.3	11.8
3	11.7	13.7
4	9.8	14.0
5	9.3	9.2
6	3.8	14.3
7	30.8	10.0
8	43.3	9.5
9	72.2	7.6

LOG SOIL SUCTION = 2.6648 -0.1277 * WC

- TABLE 2 - SOIL SUCTION AND WATER CONTENT DATA USING FILTER PAPER AND CALIBRATION CURVES

SITE: FT CARSON, CO
BOR: C-1 SAM: 10 DEP: 9.4-10.6 FT

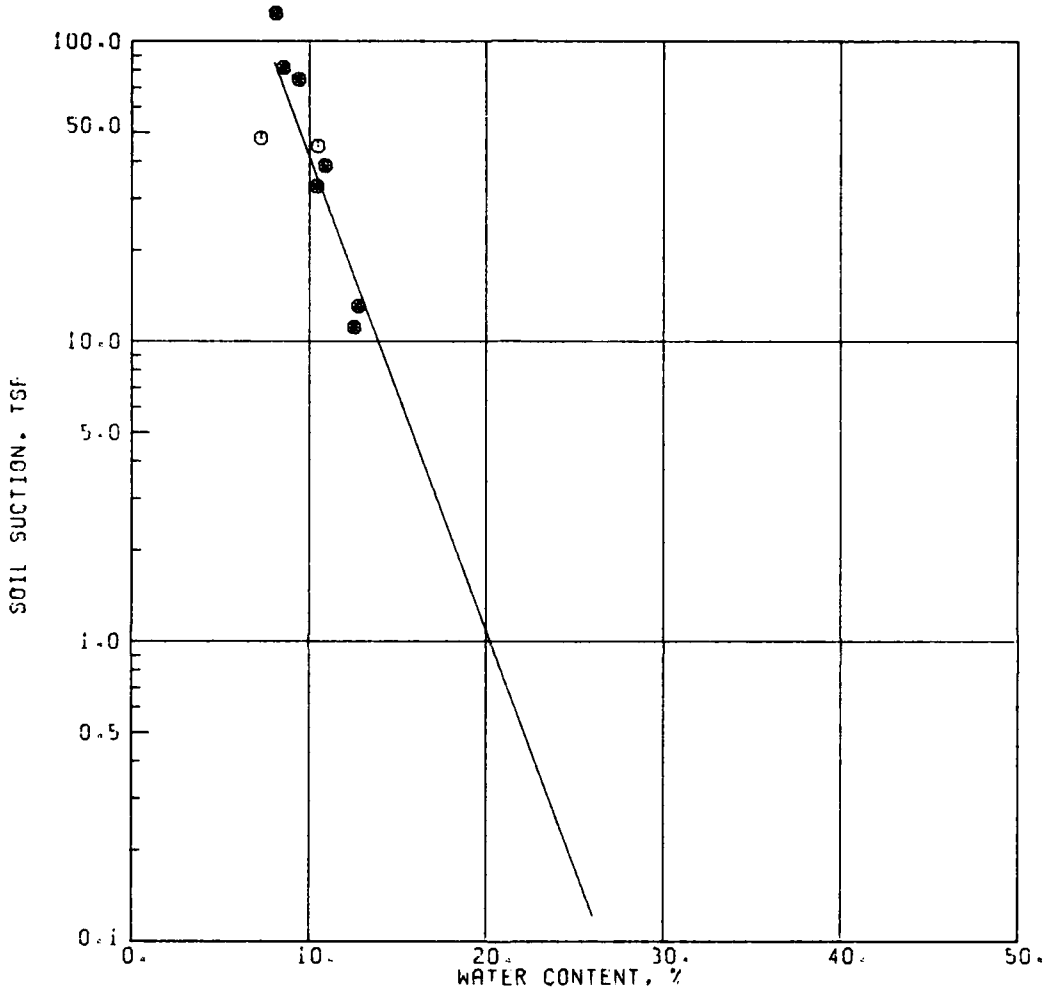
SPECIMEN NUMBER	MOISTURE CONTENT FILTER PAPER %	- - - SOIL SUCTION, TSF - - - McQUEEN/ MILLER 1968	MILLER 1978	W.E.S. I 1979	W.E.S. II 1979	Soil Water Content %
1	21.84	47.5	29.6	28.0	10.3	7.31
2	22.22	44.6	28.1	25.9	9.6	10.51
3	23.12	38.5	24.9	21.5	8.1	10.90
4	24.07	32.8	21.9	17.5	6.7	10.41
5	29.61	13.0	10.3	5.5	2.4	12.77
6	30.58	11.1	9.0	4.5	2.0	12.53
7	19.15	74.5	42.7	49.3	17.1	9.41
8	18.61	81.4	45.9	55.1	18.9	8.53
9	16.10	123.8	64.6	93.4	30.4	8.09



SOIL SUCTION VERSUS WATER CONTENT RELATIONSHIP USING THERMOCOUPLE PSYCHROMETERS

LOG SOIL SUCTION = 2.6648 -0.1277 * WATER CONTENT

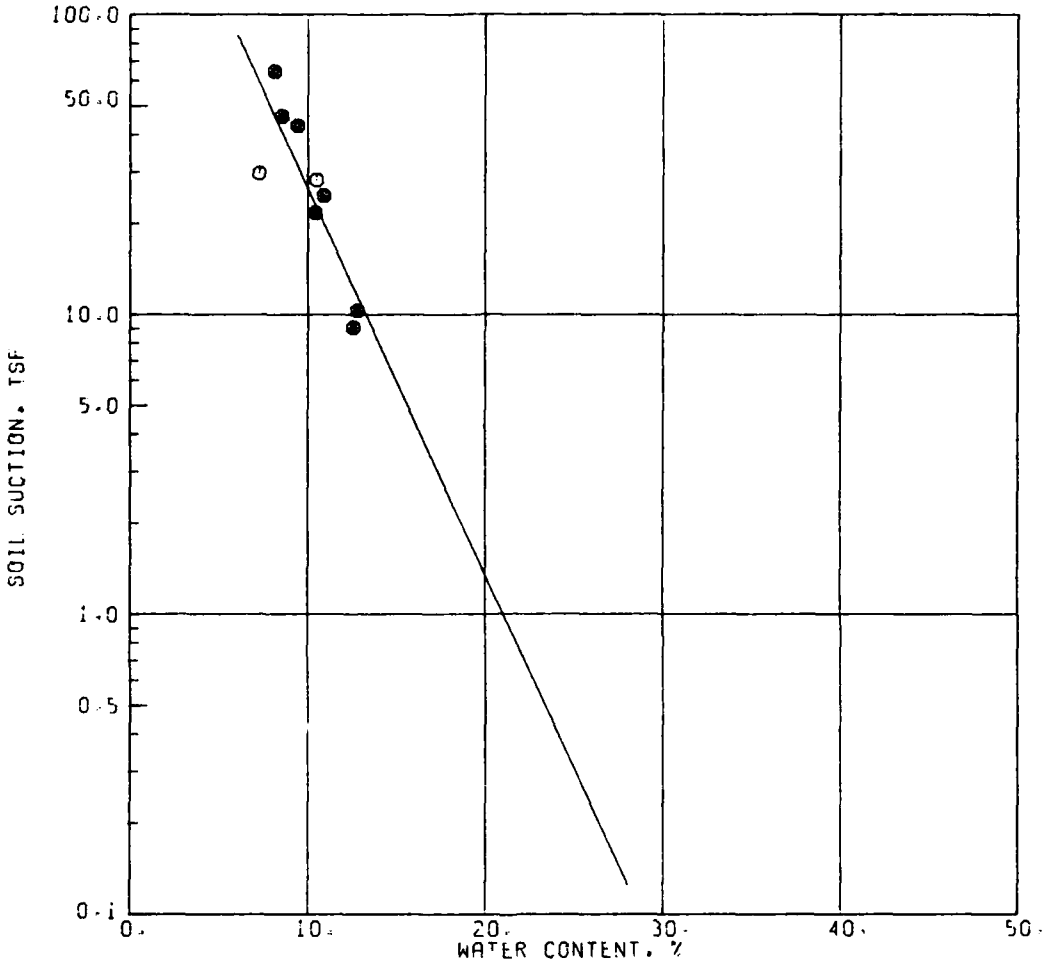
SITE: FT CARSON, CO
BOR: C-1 SAM: 10 DEP: 9.4-



SOIL SUCTION VERSUS WATER CONTENT RELATIONSHIP USING FILTER PAPER & MCQUEEN/MILLER '68 CALIBRATION CURVE

LOG SOIL SUCTION = 3.1972 -0.1582 * WATER CONTENT

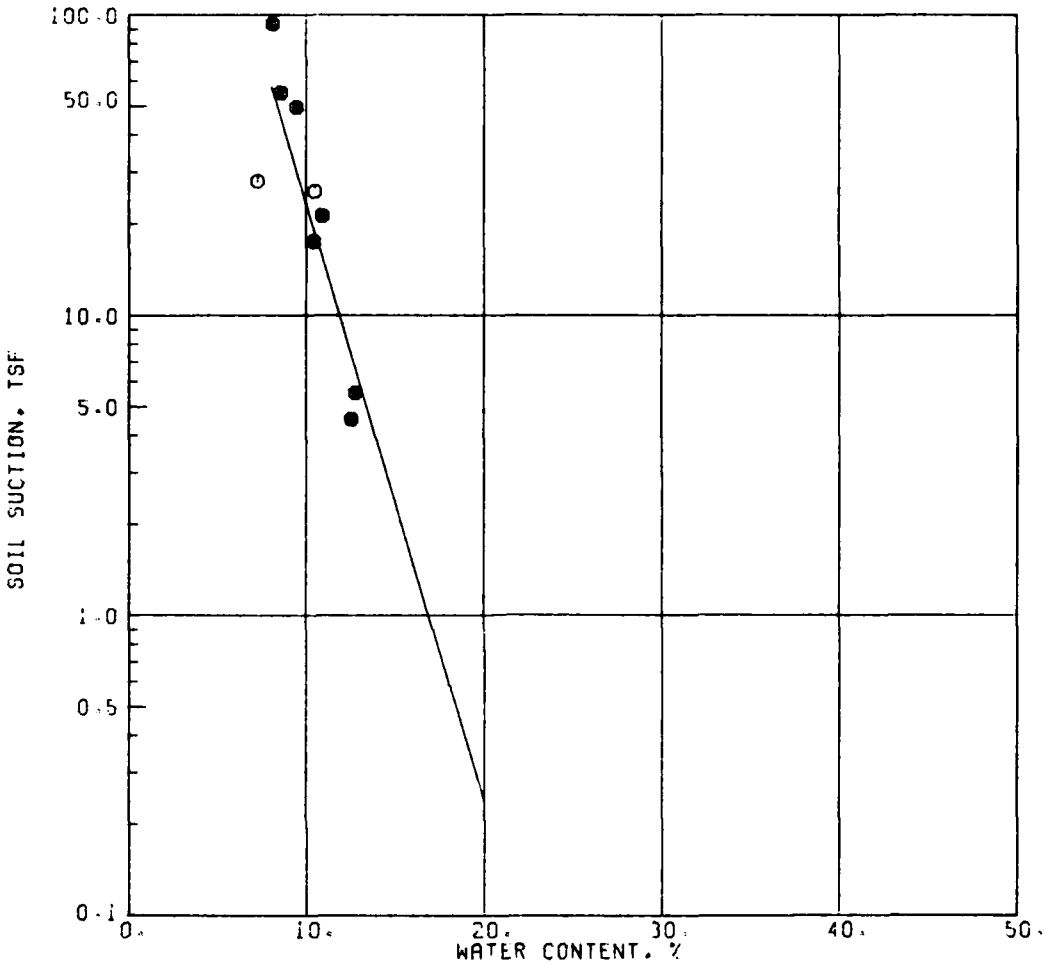
SITE: FT CARSON, CO
BOR: C-1 SAM: 10 DEP: 9.4-



SOIL SUCTION VERSUS WATER CONTENT RELATIONSHIP USING FILTER PAPER & MILLER '78 CALIBRATION CURVE

LOG SOIL SUCTION = 2.7119 -0.1291 * WATER CONTENT

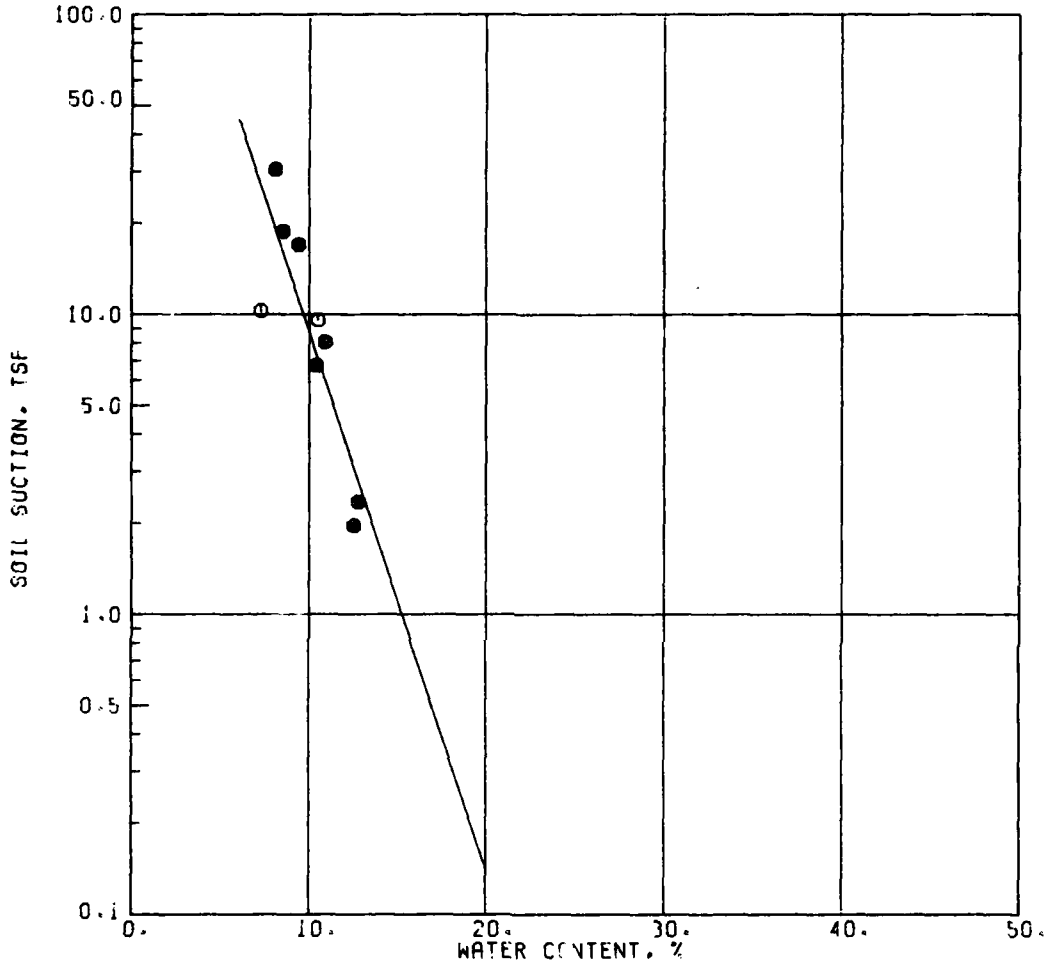
SITE: FT CARSON, CO
BOR: C-1 SAM: 10 DEP: 9.4-



SOIL SUCTION VERSUS WATER CONTENT RELATIONSHIP USING FILTER PAPER & W.E.S.-I '79 CALIBRATION CURVE

LOG SOIL SUCTION = 3.3605 -0.1991 * WATER CONTENT

SITE: FT CARSON, CO
BOR: C-1 SAM: 10 DEP: 9.4-



SOIL SUCTION VERSUS WATER CONTENT RELATIONSHIP USING FILTER PAPER & W.E.S.-II '79 CALIBRATION CURVE

LOG SOIL SUCTION = 2.7359 -0.1794 * WATER CONTENT

SITE: FT CARSON, CO
BOR: C-1 SAM: 10 DEP: 9.4-

APPENDIX C: NOTATION

A	Ordinate intercept of the soil suction-water content curve
a	Calibration constant for thermocouple psychrometers
B	Slope of the soil suction-water content curve
b	Calibration constant for thermocouple psychrometers
E_{25}	Microvolts at 25°C
E_t	Microvolts at t°C
G_s	Specific gravity
p	Vapor pressure of the pore water in the soil, tsf
p_o	Vapor pressure of free pure water, tsf
p_s	Vapor pressure of the free pore water in solution, tsf
p/p_o	Relative humidity
R	Ideal gas constant (86.82 cc-tsf/K-mole)
r^2	Coefficient of determination
T	Absolute temperature, K
t	Measured temperature, °C
v	Volume of a mole of liquid water (18.02 cc/mole)
w	Water content, percent
Δf	Free energy, cc-tsf/mole
τ° , τ	Total (soil) suction, tsf
τ_m° , τ_m	Matrix (soil) suction, tsf
τ_s° , τ_s	Osmotic (soil) suction, tsf

In accordance with letter from DAEN-RDC, DAEN-ASI dated 22 July 1977, Subject: Facsimile Catalog Cards for Laboratory Technical Publications, a facsimile catalog card in Library of Congress MARC format is reproduced below.

Snethen, Donald Ray
Evaluation of soil suction from filter paper / by Donald R. Snethen, Lawrence D. Johnson. Vicksburg, Miss. : U. S. Waterways Experiment Station ; Springfield, Va. : available from National Technical Information Service, 1980.
34, [148] p. : ill. ; 27 cm. (Miscellaneous paper - U. S. Army Engineer Waterways Experiment Station ; GL-80-4)
Prepared for Assistant Secretary of the Army (R&D), Washington, D. C., under Project No. 4A161101A91D, Task 02.
References: p. 33-34.

1. Cohesive soils. 2. Filter paper. 3. Psychrometers. 4. Soil suction. 5. Soil swelling. I. Johnson, Lawrence D., joint author. II. United States. Assistant Secretary of the Army (Research and Development). III. Series: United States. Waterways Experiment Station, Vicksburg, Miss. Miscellaneous paper ; GL-80-4.
TA7.W34m no.GL-80-4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